STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES

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INTRODUCTION TO
THE STRUCTURAL FLAKEBOARD FROM FOREST RESIDUES SYMPOSIUM

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It is my pleasure to welcome you to this symposium to discuss the wrap-up of the Forest Service program on structural flakeboard from forest residues. A real benefit of this symposium is the fact that we have most of the principal scientists involved in the research with us today. Even though each of you has been given a copy of the Proceedings of this symposium, the added feature of having these scientists with us is that they will be able to supplement their papers in the Proceedings and to answer any specific questions you might have pertaining to their area of research.

The fact that we are here today is the culmination of over 5 years of research effort by USDA Forest Service research scientists. These scientists benefitted from the results of research conducted during the past two decades by university and industrial laboratories. They also cooperated with our National Forest System, with assistance from our State and Private Forestry Branch. In fact, one of the papers being presented today is by Dr. Richard Jorgensen, who is our national wood construction specialist in State and Private Forestry. In addition to this, we have Peter Vajda, a consultant in plant and facilities, and Monte Harold, a forest industries development specialist from TVA, and Richard Withycombe from the University of Montana. We must also pay tribute to Charles Morschauser of the National Particleboard Association, who offered advice and counsel throughout the program.

This whole effort began approximately 6 years ago when, in June of 1972, Chief John McGuire approved the Close Timber Utilization Report and committed the Forest Service to a Service-wide, 5-year effort to reduce all residues on Forest Service lands. Forest residues appear in many forms. They may be dead or dying trees and cull trees. They may be trees too small to be considered merchantable by commercial standards, or trees or species which have no marketable value can be considered residues. Timber harvest results in accumulations of logging slash which can most definitely be classified as residues.

Regardless of the source of the residues, the primary purpose behind the Forest Service commitment was the need for research to upgrade the quality of environmental management and to extend timber supplies through improved treatment of forest residues whether they be logging residues or other. Many opportunities for utilizing residues were discussed, but it became apparent that structural flakeboard was the best possibility for consuming large quantities of residues as a substitute for lumber and plywood products from roundwood. So the objective to develop an economical panel product from flaked residues competitive in function and price with sheathing grade plywood was set.

A program evaluation review technique or PERT charted plan for accomplishing the objective was developed. The PERT chart plan is realistic but it is also flexible. Not too much flexibility was required. Most of the objectives or events of the plan were met on schedule. The first task defined on the chart was the establishment of performance goals for the structural flakeboard we were to develop. These goals were established in about a month by an ad hoc work group under the leadership of Con Schallau. In developing the goals for structural flakeboard, the properties of sheathing grade plywood, tempered by realistic expectations and reasonable performance requirements, were determining factors. The goals were merely meant to be targets to strive for, and were not necessarily recommendations for eventual product specifications.

Flakeboards were developed at the Forest Products Laboratory in Madison, Wisconsin, and the Southern Experiment Station's Forestry Center at Alexandria, Louisiana. Research aimed at harvesting the raw material or collecting and transporting it, and breaking it down into material for the flaker, was conducted in Houghton, Michigan; Missoula, Montana; and Alexandria, Louisiana. An important part of the program was the economic and marketing assessment of structural flakeboard. I am sure you have all noticed that a good share of this week's program is devoted to the opportunities for establishing structural flakeboard plants throughout the United States.

One of the final events of our PERT chart was the transfer of the technology developed during our program. This, of course, is why we are here today. We feel we have a good story to tell and are proud to share it with you.

This program is an excellent example of the cooperation between the branches of the Forest Service, and with the assistance of industry advisors. This spirit of cooperation is being carried

one step further in the presentation of this symposium. The USDA Forest Service and the Forest Products Research Society are cooperating in it's presentation. We were very fortunate to be able to have a co-sponsor such as FPRS helping us. It freed us of the details of site location and selection and proceedings preparation and permitted us to direct all of our efforts toward giving you a good program. So with this short introduction and welcome, I will yield the podium to Thad Harrington, who will introduce the first topic and speakers of the seminar. I hope you have an enjoyable and fruitful session.

FACTORS INFLUENCING MARKET POTENTIAL FOR STRUCTURAL FLAKEBOARD

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Abstract

The primary market opportunities for structural flakeboard are in new residential construction. Recently developed U.S. Forest Service projections show continued strong demand for single- and multi-family housing during the next five years. This increased housing demand will result in expanded markets for floor decking and wall and roof sheathing. A major factor influencing the market success of structural flakeboard in these markets will be its cost in relation to other competing board products--particularly softwood plywood. Although structural flakeboard may offer several favorable technical characteristics, it should also be competitive in price in order to penetrate most board markets.

Introduction

The success of structural flakeboard manufacture in the United States will depend on several interrelated factors such as market demand, competition from other domestic and foreign board manufacturers, building code acceptance, raw material costs, and the physical characteristics of the product. This paper will briefly discuss how these and other factors may influence the market potential for structural flakeboard.

Major Markets

The major markets for structural flakeboard include: (1) new residential construction--single-family, multi-family, and mobile homes; (2) nonresidential construction--agricultural buildings, public, commercial, and industrial buildings, concrete forms, and others; (3) industrial uses--containers and pallets; and (4) residential remodeling and repair. While all of these offer great potential for structural flakeboard, the size and complexity of each market is too large to cover in one paper. Therefore, I will concentrate on the new residential construction market. Our cooperators at Purdue University have been investigating opportunities in the nonresidential construction market and will discuss their major findings later in the symposium.

U.S. Housing Demand

New residential housing demand will be a major factor in the degree of success structural flakeboard will enjoy in the U.S. market. Although other construction markets may be attractive and offer good opportunities, the new residential housing market must be given serious consideration.

In looking back five years, it is easy to see that the housing market has been highly variable (Table 1). Fortunes are quickly made in this market and, as we saw in the 1975 recession, they are easily lost.

Construction of single-family homes, the largest segment of the market, has not only recovered from recession levels, but in 1977 advanced beyond the 1973 level. Single-family home construction in 1977 was near an all-time record of approximately 1.5 million starts (4).

Private and public multi-family housing starts in 1973 totaled 924,000 units, just slightly below the record 1.1 million units built the previous year (7). But by 1975, multi-family starts plummeted to 276,000 starts, recovering to 537,000 units in 1977.[1]

Mobile home shipments, the glamour segment of the housing industry in the early 1970's, were at 567,000 units in 1973 (7). By 1975, shipments had slid to 213,000 units, causing the closing of hundreds of mobile home plants. The mobile home industry has lagged behind the rest of the housing industry in its recovery, producing only about 277,000 units in 1977.[2] But this recovery may be better than these figures alone suggest, because many mobile home plants are now producing modular homes as well as mobile homes. Also, mobile homes are becoming larger. Single-wides are on the average becoming larger each year with 14-foot-wides now being built in almost every state. About 30 percent of all units are double-wides, which are actually houses--both in terms of construction and appearance.

Projections of new residential housing demand from 1972 to 2020 have just been published by Marcin (3). His projections show a continued strong demand for new housing during the next five years followed by a slight decline in 1984 and then a return to construction activity approximately at or slightly better than the levels posted in 1977 (Table 2). These

[1] Source: Preliminary data. U.S. Department of Commerce.

[2] Does not include prefabricated or modular homes.

productions are based on certain assumptions of population and economic growth which will not be discussed here. The detailed projections and assumptions are available in the published report (2) which is available upon request from the Forest Products Laboratory.

The demand for single-family housing units is projected to be very strong for the 10-year period, 1978-1987. Approximately 63 percent of all units built during this period will be single-family units. Since single-family units traditionally require the largest amounts of plywood sheathing and sawn lumber materials per unit, this is a very favorable market factor.

Multi-family housing demand is projected to average 555,000 units per year for the period 1977-1987. This will be about 23 percent of all residential construction (Table 2). The apartment construction activity of about 1 million units per year that we experienced for three years in the early 1970's is not likely to reoccur. In fact, the projections to 2020 show that demand at approximately one-half million units per year can be expected as normal. Thus, this should not be considered as a growth market.

The Forest Service projections of mobile home manufacture are similar to those for apartments. Their demand is anticipated to average 353,000 units for the period 1977-1987. (Production may fluctuate more than conventionally built houses from year to year because this industry is more sensitive to business cycles and it can accumulate an inventory of houses.) This will only be about 14 percent of total residential construction. However, many companies now producing mobiles will also be manufacturing modulars to help meet the growing demand of single-family homes. Since mobile home manufacturers are quick to use new materials and techniques to cut their cost, they could be a good potential market for structural flakeboard.

Regional Housing Demand

Much of the anticipated housing demand during the next decade will be centered in the South where 42 percent of the projected starts will occur and the West where 25 percent will occur (Table 2). These are regions where our softwood forest resources and industry are also concentrated, but there should be good potential for forest industry in the other regions. The North Central Region will have about 20 percent of the total demand, while the Northeast will have the remaining 13 percent.

Housing Demand and Potential Market for Structural Flakeboard

The housing demand projections discussed above, when combined with floor decking and wall and roof sheathing use factors, can be used to estimate the potential size of the residential structural board and siding market. The U.S. Forest Service has just completed a preliminary calculation of these factors by region for single-family housing, multi-family housing, and mobile homes.

Our single- and multi-family structural board use estimates include floor decking and exterior wall and roof sheathing. These estimates are based on 1976 use and are weighted to take into account the different amounts of material used in attached single-family units (such as condominiums) and detached single-family units.

Our mobile home board projections are based on a Forest Service survey conducted in 1975-76 to determine quantities of wood materials used for floor and roof decking, wall sheathing, and siding. These preliminary projections are probably conservative due to the trend in the mobile home industry toward the construction of more double-wide units which use more wood wall and roof sheathing materials than single-wide mobile homes.

The projected average annual demand for floor decking and wall and roof sheathing in the United States is 8,813 million square feet (3/8-in. basis) or 6,610 million square feet (1/2-in. basis) (Table 3). Projections of siding use were not included although a surface finish can be applied to structural flakeboard for entry into this market. The total wood siding market is very difficult to project because of the many alternatives available from plywood, hardboard, and lumber, as well as from nonwood materials. However, if siding were included, the total projected U.S. market should be in the neighborhood of 10 billion square feet (3/8-in basis) or 7.5 billion square feet (1/2-in. basis).

Regional Board Product Potential

Among the regions, the largest market is the South (Table 3). However, the South is a large geographic area compared with the North Central and Northeastern Regions. An average single-family house in the South contains fewer wood panel products than houses elsewhere, because concrete slab floor systems and concrete block and stucco wall systems are popular in many of the large markets in the South, such as Florida and Texas.

In terms of wood use, houses in the Western Region of the United States also often have characteristics similar to those in the South. Large quantities of concrete products are used in many areas, especially in the heavily populated areas in California and Arizona.

In the North Central and Northeastern States, wood structural panel use per housing unit (especially single-family units) has been very high. Based on this past tradition, the projected use for these regions shows the North Central Region to be a very good potential market for a product like structural flakeboard. However, the trend in the last year in this area is toward the use of insulating foam wall sheathing in place of traditional wood sheathing products. While few data are yet available to document the size of this material use shift, on-site observations in new housing developments suggest that the impact on markets for wood wall sheathing products could be considerable. Market inroads by foam wall sheathing could be even more significant if state and federal

minimum insulation requirements now being considered are passed into law.

One of the standards now being considered is an R-19 value for walls. (For more complete information on how to calculate resistance to the flow of heat for various wall constructions, see "How to Figure Heat Loss and Fuel Cost" (6).) Builders using conventional wall stud spacing and wood sheathing materials can obtain R value ratings just under R-19 fairly easily. But to reach values a little higher with standard wood frame and wall systems is apparently rather difficult. Builders currently advertising voluntary compliance with this standard apparently find that the cheapest method of doing this is with some foam insulation board. Therefore, while the North Central and Northeastern housing markets currently look strong based on the intensive use of structural wood panel products per individual housing unit, our projections in Table 3 could be revised downward because of a potential switch to foam wall sheathing materials.

Canadian Experience

Waferboard is the term used by the Canadian government and industry to describe their exterior particleboard intended for exterior sheathing uses (2). Waferboard has been manufactured in Canada since the beginning of the late 1960's. A Canadian government study published in 1975 reported six plants either under construction or in production with an estimated 1976 annual capacity of about 600 million square feet (3/8-in. basis) (Table 4) (2).

During all or most of 1977, the waferboard plant at Lesser Slave Lake was not in production. However, officials of the Canadian Department of Industry, Trade, and Commerce, in telephone conversations with the author, reported this plant is well maintained and capable of resuming production on short notice.

Statistics Canada reported that in 1976, 356 million square feet (3/8-in. basis) of phenolic-bonded particleboard was produced in Canada, of which 322 million square feet were shipped to both domestic and foreign markets (5). Canadian government sources unofficially estimate that about 50 percent of these shipments were to U.S. markets.

For 1977, Statistics Canada reported phenolic-bonded particleboard production was 409 million square feet (3/8-in. basis) while shipments were 434 million square feet (5). It was unofficially estimated that about 55 percent of these shipments or about 240 million square feet were exported. These exports were most likely to U.S. markets.

Major Markets[3]

Waferboard in Canada is widely used in residential construction for sheathing applications. In single-family and low-rise multi-family housing, it is frequently used for exterior wall and roof sheathing—generally replacing sheathing-grade plywood. Some waferboard is also replacing "soft" wood fiber insulation board which is currently used as sheathing. According to the Canadian Department of Industry, Trade, and Commerce, waferboard is not widely used for floor decking. Other related residential uses are for garden sheds and fencing privacy screens. Waferboard is also reported to be used in mobile and modular construction and in the construction of barns and other farm buildings.

Waferboard is also used in Canada for packaging and crating. This market could be very promising in the United States, especially in the shipment of agricultural products.

Pricing[3]

Waferboard in Canada is generally sold at prices competitive with plywood which would be used for the same purpose. Because most of Canada's larger markets are in the East--particularly Quebec and Ontario--waferboard has a freight cost advantage over plywood which is produced mostly in British Columbia. Thus, the delivered cost of waferboard as compared with softwood plywood is considered to be a major factor influencing the popularity of waferboard in Canada.

Convenience of Delivery[3]

Another factor favoring waferboard in Canada relative to softwood plywood is said to be rapid delivery from plant to construction site. Because of the close proximity of the waferboard plants to some of the major Canadian markets, overnight truck delivery is said to be possible.

U.S. Situation

Production

Structural board has been commercially manufactured in the United States since the early 1970's. The primary manufacturer has been Blandin Wood Products Company of Grand Rapids, Minn. The annual capacity of this plant has been estimated at several different quantities by the trade press. Most estimates of annual plant capacity are in the range of 30 to 60 million square feet (3/4-in. basis).

Price Strategy

The question of how a new product should be priced is always near the top of the list of difficult decisions that must be made by corporate leaders. One of the better references on the subject that can be recommended is Dean's paper "Pricing Policies for New Products" (1). The article has been widely referenced as one of the best commentaries on this very complex subject. It was recently updated by Dr. Dean and republished as a Harvard Business Review Classic.

Dean points out that new products can often be priced high when they are first introduced to the market if they are distinctive from their

[3] Based on telephone conversations with officials of Canada's Department of Industry, Trade, and Commerce.

competition. However, as competing manufacturers enter the market, it is difficult to maintain the high initial price strategy. Furthermore, Dean states:

> The seller's zone of pricing discretion narrows as his distinctive "specialty" fades into a pedestrian "commodity" which is so little differentiated from other products that the seller has limited independence in pricing, even if rivals are few (1).

Thus, it would appear from these statements and the Canadian experiences that structural flakeboard will have to be priced competitively with softwood plywood (CD Exterior) in order to penetrate the major residential housing markets. This, indeed, appears to be the current pricing situation for Canadian waferboard currently sold in the United States. However, there are no specific data available on waferboard price trends in the United States.

Softwood Plywood Prices

Since structural flakeboard will in all likelihood be competing with softwood plywood at least in part on the basis of price, it is appropriate to look briefly at plywood prices over the last 10 years. Prices of Douglas-fir plywood, 1/2 inch, standard exterior (3-ply) 1,000 square feet, were quite variable during the 1967-1977 period--ranging from less than $60 in 1967 to about $240 this last year (Fig. 1). Thus, if structural flakeboard manufacturers must follow the plywood industry's price leadership, they should be ready to make rapid and frequent price adjustments. Added structural board capacity in the United States may serve to dampen these wide price variations--especially upward movement during periods of strong demand over a relatively short time period. But this potential benefit would be difficult to predict at this time.

Building Codes

Since Dr. Jorgensen will provide us with the details on the status of code acceptance, I will only say that this is an important factor influencing the potential of structural flakeboard in most markets. Without proper code approval or if the status of code approval is in a state of confusion, the product will be handicapped severely in the marketplace. Potential users will simply not take a chance on having problems.

Favorable Physical Characteristics

Structural flakeboard has characteristics that should help it compete favorably with softwood plywood. All structural flakeboard will have a solid surface. This should help it compete in the floor decking market. Its relative stiffness gives it a solid feel underfoot when used as floor decking. This characteristic is also desirable in the roof decking market. Finally, structural flakeboard is a "solid core" product. This should prove to be a good all-around advantage.

Individual Panel Weight

Structural flakeboard panels will tend to be heavier than their plywood competitors. Panels with large ratios of hardwood to softwood flakes will probably be noticeable to carpenters. Although this is a factor to take into consideration, there is no indication at this time that carpenters will not use the material on this basis. But, it could cause some re-evaluation of roof truss design.

Summary and Conclusions

The projected strong demand for housing over the long run in the United States is an important and favorable factor for potential manufacturers of structural flakeboard. New single-family housing is projected to lead this demand trend which will provide a good opportunity for structural flakeboard to share in this large floor decking and sheathing market.

The South and West will be the regions where single-family housing starts will be largest and hence will provide the largest floor decking and sheathing market. However, the North Central states will also offer good market opportunities, perhaps as good as the southern and western regions considering the total size of each geographic area. An analysis of recent floor decking and sheathing use data shows that individual single-family housing units in the North Central and Northeast use much more of these materials per unit than in other regions. However, foam insulation sheathing materials are making a strong bid for the exterior wall sheathing markets in these northern regions.

Canada has been producing waferboard since the late 1960's. Estimated total Canadian capacity is estimated at about 600 million square feet (3/8-in. basis). Most of this plant capacity is located in the Canadian Midwest relatively close to major Canadian and U.S. markets. Total Canadian shipments of waferboard in 1976 were 322 million square feet and in 1977, 434 million square feet (3/8-in. basis). At least 50 percent of these shipments were to U.S. markets. Waferboard in Canada is widely used for wall and roof sheathing and to a lesser extent for floor decking in both single- and multi-family housing. It is generally priced to be competitive with softwood plywood.

The pricing strategy for structural flakeboard in the U.S. market will probably be that prices be set competitive with softwood plywood of similar grade. Thus, production cost targets should be set as low as possible, taking into consideration the wide price variation of plywood over the past 10 years.

Perhaps the overriding factor in favor of the development of a structural flakeboard industry in the United States is the favorable outlook for the housing industry. It is always much easier to launch a new product when the market is growing than when it is in a downturn period. Thus, the timing may be quite good to begin the development of the industry now.

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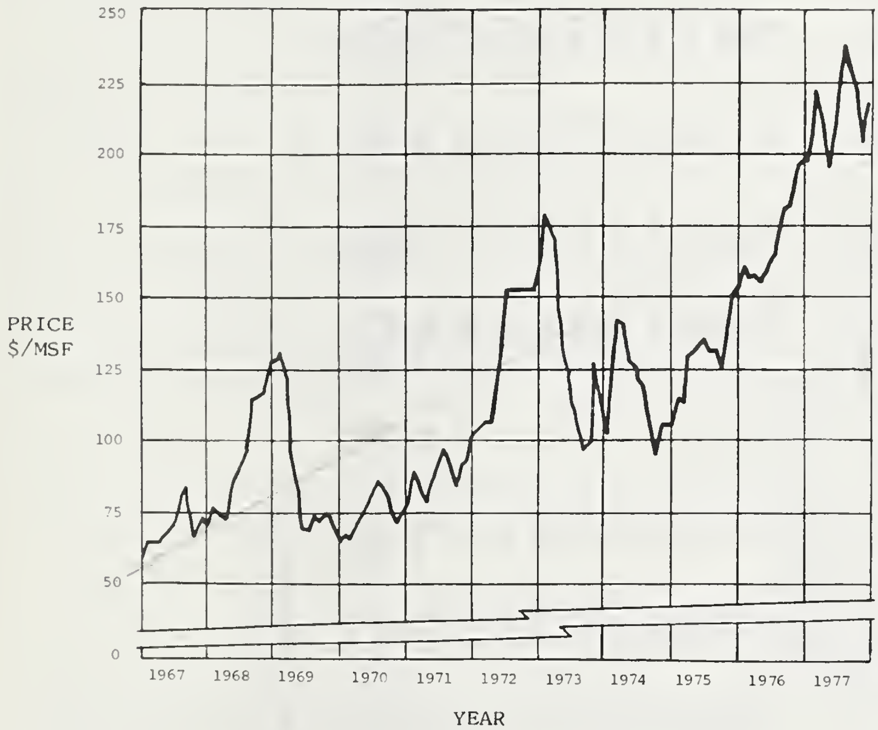

Figure 1.-Average price (f.o.b. mill) of Douglas-fir plywood, 1/2 inch, Standard Exterior (3-ply) for 1967-1977.

Table 1. — NEW HOUSING ACTIVITY IN THE UNITED STATES, 1973-77

Year	New public and privately owned housing starts and mobile home shipments				
	Total all housing types	Total single and multi-	Single-family units	Multi-family units	Mobile home shipments
	(in thousands of units)				
1973[1]	2624.4	2,057.5	1,133.2	924.3	566.9
1974[1]	1681.7	1,352.4	889.1	463.3	329.3
1975[1]	1384.1	1,171.4	895.5	275.9	212.7
1976[1]	1793.7	1,547.6	1,166.4	381.2	246.1
1977[2]	2266.1	1,989.3	1,451.9	537.4	276.8

[1]Source: U.S. Dept. of Commerce. Bureau of Census 1977 (7).
[2]Source: By telephone--U.S. Dept. of Commerce. Bureau of Census.

Table 2.--Number and percent of new housing units projected for the United States by Census Region and type of unit, 1978-87

Year	Projected new housing demand by census region[1/]																
	Grand total all types[2/]	Northeast				North Central				South				West			
		Total all types[2/]	Single family units	Multi-family units	Mobile homes	Total all types[2/]	Single family units	Multi-family units	Mobile homes	Total all types[2/]	Single family units	Multi-family units	Mobile homes	Total all types[2/]	Single family units	Multi-family units	Mobile homes
	(In thousands of Units)																
1978	2,215	297	149	118	31	463	287	108	68	915	595	172	147	540	320	136	83
1979	2,362	325	161	132	32	495	304	120	71	969	622	191	157	573	335	150	89
1980	2,423	332	164	135	33	504	309	123	73	996	637	198	161	590	343	155	92
1981	2,466	335	167	135	33	508	313	122	73	1,016	655	197	164	606	357	157	93
1982	2,562	348	181	134	32	527	339	116	72	1,056	713	181	161	631	390	149	92
1983	2,611	349	183	134	33	534	345	116	72	1,080	734	182	164	647	402	152	93
1984	2,474	310	162	117	31	493	318	105	70	1,044	713	171	160	627	392	143	91
1985	2,525	312	164	117	31	501	326	105	70	1,069	737	171	161	643	406	145	92
1986	2,537	307	163	113	31	498	328	101	69	1,080	757	163	160	652	419	141	92
1987	2,542	301	161	110	30	493	327	98	68	1,089	771	159	159	658	428	139	92
Totals	24,717	3,216	1,655	1,245	317	5,016	3,196	1,114	706	10,314	6,934	1,785	1,594	6,167	3,792	1,467	909
Percent		13.0	6.7	5.0	1.3	20.3	13.0	4.5	2.8	41.7	28.1	7.2	6.4	25.0	15.3	5.9	3.7

1/ Source: Outlook for Housing by Type and Unit and Region (3).

2/ Totals were computed from unrounded figures.

Table 3.--Average annual projected floor decking, wall and roof sheathing demand in the United States by region and housing type for the period 1978-1987.

Region	Housing type							
	Total all types		Single family units		Multi-family units		Mobile homes	
	(3/8-inch basis)	(1/2-inch basis)	(3/8-inch basis)	(1/2-inch basis)	(3/8-inch basis)	(1/2-inch basis)	(3/8-inch basis)	(1/2-inch basis)
	(In millions of square feet)							
Northeast	1,293	970	976	732	248	185	69	52
North Central	2,089	1,567	1,690	1,268	246	185	153	145
South	3,403	2,552	2,715	2,036	342	257	346	260
West	2,027	1,520	1,542	1,157	288	216	197	148
Total	8,812	6,609	6,923	5,192	1,124	843	765	574

Source: U.S. Forest Service preliminary estimates.

Table 4. — CANADIAN WAFERBOARD PLANT CAPACITY, CORPORATE NAME AND LOCATION OF PLANTS, 1976

Estimated plant capacity	Company name	Location
(Million sq. ft. 3/8-in. basis)		
100-110	Alberta Aspen Board, Ltd.	Lesser Slave Lake Alberta
100-110	Great Lakes Paper Co.	Thunder Bay, Ontario
120-130	MacMillan Bloedel, Ltd.	Hudson Bay, Saskatchawan
100-110	MacMillan Bloedel, Ltd.	Thunder Bay, Ontario
45-50	Waferboard Corp., Ltd.	Timmins, Ontario
100-110	Weldwood of Canada, Ltd.	Longlac, Ontario

Source: Department of Industry, Trade, and Commerce and Department of Regional Economic Expansion (2).

REQUIREMENTS, CODES, AND FOREST SERVICE GOALS

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Abstract

When the original planning group was established there was only one structural board being produced in the country. Our economists predicted growing and continuing shortages of veneers for structural panels and there were large volumes of forest residues to be used. Performance criteria and goals were established by engineering analysis. Some targets needed more research. Stronger and weaker panels were meeting existing model code and Commercial Standard requirements. New composites were also obtaining code approval. The challenge was to produce from forest residues the best boards possible, designed to meet properties our best engineering judgement deemed would probably and possibly serve structural end uses. We feel the research data you will hear about will provide a basis for producers to manufacture boards from residues to meet model code acceptance standards.

To put the research results you will be hearing about later in this symposium into perspective, I must go back to the inauguration of the Task Force and describe its development in relation to my topic. What was the status quo of structural particleboard back in June 1972 when the original Close Timber Utilization Report was approved? It was something like this:

1. There was almost universal code acceptance of phenolic particleboards, some with overlayments, for exterior siding. These were not structural boards but their good record in exposure situations showed a phenolic board would stand up.

2. There was FHA and ICBO acceptance of a planer shaving board made on the west coast. Approval was for thickness equal to plywood only for flooring. The wall and roof sheathing thicknesses required severely limited its use because of the extra weight involved.

3. No other structural boards were being produced in the United States but both waferboard and veneered particleboard were about to appear on the market from domestic factories.

4. Waferboard had been on the market in Canada for over five years and was supplying a surprisingly large percentage of the sheathing market there after that short time. It was FHA approved for roof and wall sheathing in the same thicknesses as used in Canada.

5. The seventh Particleboard Symposium was about to be held at Washington State University where several engineers would discuss their approaches to basic engineering factors involved in the use of particleboard as a structural material.

Also at that time our economists encouraged the development of structural particleboard and our resource people confirmed a growing and continuing shortage of veneers over the long-time picture, with no slacking of housing and other construction requiring panels. We knew we had much standing and down forest residues and competent scientists to cover all aspects of the development of structural boards from forest residues so the Chief of the Forest Service appointed a planning group in February 1973 and our effort was underway.

The first collaborative work of the group was the development of a Program Evaluation Review Technique chart. A PERT chart is a management technique to control large, complex projects and in our case held dates and responsibilities for each step of the envisioned five year plan. The schedule was adhered to and this seminar is being held only two months after the PERT chart calls for the technology transfer. Although modified somewhat over the years it was an excellent control tool.

Two critical paths were involved; the development of panels, and a residue resource review and recovery strategy. Along the panel development control path the first item allowed two months for the formulation of performance goals. Without a dated literature review, what were some of the general aspects to consider in this formulation? We could see that:

1. One material, plywood, was already serving in the capacity visualized for structural particleboard and its physical and mechanical properties provided an indication of the type of material which could do the job involved. However, it was realized there were certain limitations on the production of boards from residues and it would probably be impossible to duplicate completely the properties of plywood.

2. Waferboard, less stiff and less strong than plywood, was performing

satisfactorily in Canada and was FHA approved.

3. A Commercial Standard was, and still is, in existence describing a phenolic board which could be used for structural pruposes but no code body had approved such a board in equivalent thicknesses to plywood.

4. The major model codes all had floor, wall and roof strength and stiffness requirements which would have to be met by a marketable product. This was a doubly restrictive condition in that it affected both the physical and the mechanical properties and held a still unanswered question as to what the building industry would accept in a panel product. It was also probably the most important consideration since we knew that without code approvals the product would never be able to be widely used.

We viewed the challenge as one that required we produce the best boards possible, not necessarily equal in all properties to plywood, but sufficiently designed to meet properties the best engineering judgement of the day could give us about a product that possibly and probably could and would serve the same end uses.

So a group of our engineers developed performance criteria for six major properties. Each area included state-of-the-art proposals based on past research results, recommended design and analysis methods and recommendations for future research where deemed necessary. Items such as safety factors as an engineering judgement and load duration factors which would be determined by future research were necessarily part of these calculations. The performance goals set up for the Task Force as a result of these studies were as follows:

Modulus of Elasticity	800,000 psi
Near Minimum Modulus of Rupture (5% Exclusion Level)	4500 psi
Internal Bond	Dry-70 psi After D1037-30 psi
Linear Expansion 30-90% RH	4 x 8, 4 x 9-0.25% Over 9' - 0.20%
Thickness Swell 30-90% RH	8.0%
Lateral Racking	FHA Tech. Circular No. 12
Time Dependent Deflection	Research Needed
Direct Nail Withdrawal (All nails driven dry)	Dry-40# 24 Hour soak-25# After D1037 Acc. Expos. - 20#
Density	Up to 40 lb./cu.ft.
Impact	National Housing Agency Performance Standards until further research done.
Fire and Smoke	NFPA Life Safety Code

These are the targets we have been aiming at. How close we have come will be reported in detail as the seminar continues.

Meanwhile, the plywood shortage occurring in late 1972 and early 1973, at the time these goals were being developed, led to an increased market for waferboard on the east coast and particularly in the state of New Jersey. In late 1972 the New Jersey State Building Code approved the use of Canadian waferboard for sheathing in thickness dimensions equivalent to those in use in Canada and equivalent to the FHA approval memorandum. Many carloads of the material were brought into the state and were widely used by both large and small builders. As plywood production began to catch up with the shortage, the supply and the price differentials between the two disappeared and some builders went back to plywood while others continued to use the waferboard. Waferboard continued to be used under the FHA Memorandum Approval until 1975 when a formal Materials Release was issued.

Also during this five year period west coast model code approval was obtained for both oriented particleboard and veneer-faced oriented particle coreboard. The properties of both these boards are considerably higher than possible with a standard random particleboard and close to those of plywood. The veneer faced board has since then been approved by other model code bodies.

Encouraged by the east coast acceptance of waferboard, the Canadian producers applied for approval to the Building Officials and Code Administrators International, the Southern Building Code Congress, and to the International Conference of Building Officials and as of this date have received appropriate approval from each of these model codes. A U.S. produced waferboard is also approved by BOCA. These boards are approved for roof sheathing at 3/8" on 16" O.C. rafters and 7/16" on 24" O.C. rafters and as wall sheathing 5/16" on 16" O.C. studs and 3/8" or 7/16" on 24" O.C. studs without corner bracing. These boards conform to type and grade 2B2 of CS236-66 which calls for minimum averages for Modulus of Rupture of 2500 and Modulus of Elasticity of 450,000. Actual production boards usually run about

600,000 Modulus of Elasticity. A satisfactory service record of the waferboard in Canada and in the United States has helped gain approval of this board.

The regulatory community and a growing segment of the market place have then, five years after the Task Force establishment, accepted boards with properties exceeding the original goals of the Force and boards considerably lower than those goals. With 100 percent accurate hindsight it appears now, five years later, that the Task Force got off to a good start in its direction. The scientists will explain in detail how their results have satisfied the goals set for them and the new developments which were indirect ramifications of attempts to meet those goals.

Since we now have nationwide model code acceptance and widespread local code acceptance of boards for roof and wall sheathing which are considerably less stiff and less strong than those developed by this Task Force, we are confident that research data that you will hear about at this seminar will provide a basis for producers to manufacture boards from residues to meet model code acceptance standards. The engineering data used in formulation of the goals included use as floor panels. When you hear the accomplishments of our scientists you can form your own opinions on floor panel applications. At this time we are doing and supporting further work on other uses for the types of boards made from residues. Some of their characteristics certainly make it seem possible that there will be expanded uses in the future for these types of engineered panels.

FIBER FOR STRUCTURAL FLAKEBOARD--MECHANIZED THINNING AND TOPWOOD RECOVERY

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Abstract

Case studies in mechanized thinning of pole-sized hardwoods by the Forest Service's engineering research project at Houghton, Michigan, have demonstrated that significant amounts of thinnings can be recovered economically by a completely mechanized system and still improve the residual stand quality and growth. Additionally, an experimental topwood processor has shown considerable promise in recovering massive hardwood tops and limbs. A new chipping machine was developed that turns residue into particles suitable for subsequent ring flaking and use as structural flakeboard furnish.

Introduction

In 1973 the Forest Service organized the Close Timber Utilization (CTU) program to improve forest utilization and reverse the present practice of ignoring those forest residues which are normally left in the woods to rot. Included are the unsightly logging residues, slash, and standing dead and dying trees. Part of the reason for leaving these residues behind was the questionable economics of recovery and lack of viable markets.

An integral part of the CTU program was a service-wide, multidisciplinary research program to develop the technology to make the use of forest residues for structural flakeboard economical. The implications of such a revolutionary development are exciting since exterior grade structural plywood, which normally requires straight, high quality, peeler bolts, could be replaced by an engineered flakeboard made from logging waste, small diameter or crooked materials. Additionally, the benefits derived from extending quality timber supplies are equally exciting. Three broad problems need solutions: 1) the development of flakeboard performance requirements; 2) development of methods for harvesting, processing, and transporting forest residues; and 3) development and evaluation of structural board from residue-derived flakes.

The Forest Engineering Laboratory, located in Houghton, Michigan, which conducts research to promote more efficient mechanization of forestry operations in the North Central States, was charged with two principal tasks in this forest residues to flakeboard program. The first was to identify and assess those wasted residues which could furnish significant fiber for structural flakeboard and to conduct research on new systems and equipment concepts to permit economical recovery of these residues. The second mission was to develop a machine capable of field chipping typical residues and small diameter trees for transport to a mill and conversion into flakes for flakeboard.

Two high-volume residues were chosen: 1) thinnings from pole-sized northern hardwood stands, and 2) tops and limbs from conventional hardwood sawlog operations. The foresection of this paper presents the results of research to recover these two problem forest residues. The second section discusses the development of an experimental spiral-head chipper to render these forest residues into particles suitable for ring flaking.

Mechanized Thinning of Pole-Size Northern Hardwoods

The Forest Service's "Outlook for Timber" report (14) details the supply/demand forecasts for hardwoods as well as the general condition and quality of our hardwood forests. The projected demand for hardwood to year 2000 is expected to increase more than two-fold, to reach 7 billion cubic feet. Of this, 19 billion board feet is the expected demand for hardwood sawtimber. A direct comparison of supply/demand statistics could yield misleading conclusions. The fact is, although we are currently growing more hardwood volume than is being harvested, there is a definite decline in the quality of hardwoods. Much of the hardwood growth and available supply is in small trees or species with limited markets; large trees of preferred species are in short supply in most hardwood areas. Problems of supply are compounded by a declining land base caused by increasing public pressures for agriculture, recreation, wilderness, and wildlife.

In the Northeastern United States there are approximately 32 million acres of the maple-beech-birch forest type, approximately 9 percent of the eastern forest land area (10). In the Lake States area of Michigan, Wisconsin, and Minnesota, approximately 23 million acres out of about 50 million acres of commercial timberland are classified as poletimber (table 1). Much of this poletimber currently needs thinning. Additionally, over 14 million acres of

Table 1. -- LAKE STATES COMMERCIAL TIMBERLAND. (14)
(Millions of acres)

State	All classes	Poletimber	Seedlings and saplings
Michigan	18.8	8.1	5.5
Wisconsin	14.5	6.6	4.5
Minnesota	16.9	8.4	4.2
Total	50.2	23.1	14.2
Percent	100	46	28

Table 2. — STOCK AND STAND TABLE (PER ACRE) FOR ENTIRE 50 ACRES BEFORE THINNING (2)

D.b.h. (inches)	Sugar maple Trees	Sugar maple Volume	Sugar maple Volume (25 percent of trees)	Red maple Trees	Red maple Volume	Red maple Volume (55 percent of trees)
	No.	Cords	Bd. ft.	No.	Cords	Bd. ft.
5- 9	35.32	1.65	--	83.72	4.08	--
10-14	13.17	1.07	295	34.54	3.42	384
15-19	4.46	0.06	707	1.62	0.08	204
20+	0.55	--	125	0.10	--	23
Total	53.50	2.78	1,127	119.98	7.58	611

D.b.h. (inches)	Other species[1] Trees	Other species[1] Volume	Other species[1] Volume (20 percent of trees)	Total Trees	Total Basal area	Total Volume	Total Volume
	No.	Cords	Bd. ft.	No.	ft^2	Cords	Bd. ft.
5- 9	17.55	1.16	--	136.59	37.49	6.89	--
10-14	21.38	1.68	485	69.09	45.55	6.17	1,164
15-19	3.42	0.29	383	9.50	14.63	0.43	1,294
20+	0.32	--	66	0.97	2.29	--	214
Total	42.67	3.13	934	216.15	99.96	13.49	2,672

[1]In the western Upper Peninsula of Michigan these second growth hardwood stands are primarily composed of sugar maple (Acer saccharum), red maple (Acer rubrum), and yellow birch (Betula alleghaniensis). There are lesser amounts of black ash (Fraximus nigra), American elm (Ulmus americana), black cherry (Prunus serotina), hemlock (Tsuga canadensis), balsam fir (Abies balsamea), and red oak (Quercus rubra). The maple, oak, birch, and cherry are valuable commercial species commanding a high price when saw log size.

seedlings and saplings will need future thinning. Crowding becomes serious, long rotations are frequently required to produce merchantable timber, and stagnation may occur on poor sites resulting in a deficient, unmerchantable stand. Further, many trees are sprouts and are of poor form, forked, short, and generally worthless as sawtimber if left to mature. Limited acreages of these stands are actually thinned each year to promote quality growth. Trees felled in thinning are traditionally left in the forest to decay. This thinning practice, although it ultimately improves the stand, yields no immediate net return to the landowner. It is but a direct outlay of capital.

A concerted effort is needed to improve the quality and quantity of hardwood stands--a dedicated program of thinning of pole-size hardwoods for timber stand improvement (TSI). However, the major hurdles to dedicated TSI are economics and markets.

Selective chain saw thinning, besides being wasteful, is very labor intensive and costly. Typical costs for chain saw thinning in Michigan range from $25 to $35 per acre. The practice of TSI in northern hardwoods must be transformed from a labor intensive, costly, and wasteful practice into a completely mechanized system geared to profitable recovery of thinnings.

Mechanized Thinning Case Study

The North Central Forest Experiment Station's Forest Engineering Laboratory, in cooperation with the Michigan Department of Natural Resources, investigated the productivity and economics of mechanically thinning northern hardwoods. A poletimber stand in Ontonagon County, Michigan, was thinned during the fall of 1974 (2). The study objective was to demonstrate the commercial viability of mechanized TSI whereby the thinned products from second-growth, northern hardwood pole stands are recovered at a profit. Although the recovered thinnings from the case study were converted to pulp chips because a market existed, such thinnings could as well be converted to a product form more suitable as furnish for structural flakeboard. Conventional pulp chips are not suitable for flaking. Production of a "fingerling" particle which can be ring flaked will be discussed later.

Stand Description and Thinning Treatment

A 50-acre stand of mixed species, predominantly pole size, on essentially level terrain with well drained, sandy loam was selected in the Mishwabic State Forest in Michigan's Upper Peninsula (fig. 1A). A preliminary survey indicated 13 cords of hardwood pulpwood and 2,700 board feet of small sawlogs per acre (Table 2). Initial basal area was about 100 square feet per acre in trees 6 inches d.b.h. or larger. Although tree diameters ranged from less than 2 inches d.b.h. to 28 inches, average tree diameter was slightly less than 6 inches. The stand, which was equally bisected by an existing woods road requiring improvement, was further divided into ten 5-acre plots measuring 330 feet wide by 660 feet deep. Landings were located at each end of the woods haul road bisecting the stand.

Five thinning treatments, four fully mechanized, were tried with two replications per treatment. The mechanized treatments were: 1) strip thin only; 2) strip thin with selection thin between strips; 3) selection thin only; and 4) a shelterwood cut. The base treatment was a conventional chain saw TSI cut where the felled trees were left on the forest floor (fig. 1B).

The stand was thinned to a residual target basal area of 65 square feet with the exception of the shelterwood cut which was cut to a 70 percent crown cover. In shelterwood cutting the purpose of the first thinning cut is to remove a certain portion of the overstory to open up the stand but still leave a residual overstory to provide seed and shelter for establishment of new growth.

Equipment

Conventional equipment was used to thin the test tract. The three major pieces of harvest equipment used were: 1) a John Deere 544 feller buncher with a Rome accumulator shear (fig. 1C); 2) a Clark Ranger 667 grapple skidder; and 3) a Trelan D-60 whole-tree chipper.[1]

Productivity

Of the test treatments, strip thinning with selective thinning in the leave strip (fig.2) proved most promising because it produced the most chippable wood, was the easiest to do in terms of men and machines, caused the least damage to the residual stand, and left the residual stand esthetically pleasing. The second favored study treatment was the sheltered cut (fig. 1D). The total yield of chips and sawlogs on the nominal 40 acres mechanically thinned was 1829 green tons (table 3). The majority was in material converted to chips. Approximately 3 percent of the total recovered tonnage was sorted out at the woods landing as saw-

[1]Mention of trade names are for convenience and do not constitute the endorsement of products by the U.S. Government.

Table 3. -- MATERIAL RECOVERED FROM MECHANIZED HARDWOOD THINNING.[1/] (2)

Treatment and size (acres)	Chips removed	Saw logs removed	Total removed	Tons per acre	Stems per acre
	tons	bd. ft.	tons		
Strip (10.5)	342	2,760	359	34.2	186.2
Shelterwood (9.6)	470	2,670	486	50.6	255.0
Selective (9.5)	444	1,380	453	47.7	219.2
Strip with selective (9.5)	513	2,830	531	55.9	263.9
Total	1,769	9,640	1,829		
Average				46.8	230.0

1/ All tonnages are green weight.

Table 4. -- BREAKDOWN OF 1974 MECHANIZED THINNING COSTS (3)

(Dollars/Green ton)[1/]

Item	Equipment	Labor	Total	Percent of total
Feller-buncher	1.13	.68	1.81	21
Skidder	.94	.68	1.62	19
Chipper	1.29	.68	1.97	22
Chain saw	.03	.27	.30	3
Maintenance and fuel truck	.06	.41	.47	5
Chip van	.48	.31	.79	9
Highway truck	1.40	.31	1.71	20
Landing truck	.04	.07	.11	1
Total	5.37	3.41	8.78	100

1/ Average of all thinning treatments on 40 acres.

Table 5. TWO-YEAR DIAMETER GROWTH FOLLOWING MECHANIZED THINNING [1/]

Species	Strip only	Strip w/select.	Select. only	Shelterwood
	- - - - - - - - - -inches- - - - - - - - - -			
Sugar Maple	0.150	0.062	0.100	0.220
Red Maple	.164	.200	.178	.244
Black Cherry	-	.267	.400	.200
Red Oak	.200	-	1.100	.600
Hemlock	.100	-	-	.100

1/ First retally of 4 selected compartments.

logs. The average yield per acre was 46.8 green tons from 230 stems. The strip with selective thinning between strips averaged 55.9 tons per acre from 264 stems. Hourly productivity ranged between 13 to 26 green tons per hour and averaged 17 tons per hour.

For the various thinning treatments under which the feller buncher with accumulating shearhead operated, the stem productivity ranged between 2.7 to 2.9 stems per cycle which did not make up a skidder load. The stems per skidder load generally ranged between 9 to 11 trees which in turn ranged in weight between 1.7 to 2.6 green tons. Total skid time varied between 6 to 11 minutes including delays. The average number of stems per vanload was 116 stems which took 84 minutes to chip conventionally and fill a 20-ton van.

The schematic of figure 2A shows why the strip with selection system was preferred. Initially the feller buncher starts cutting a 10-foot wide strip laying all shear accumulator bunches to the right. At the end of each strip (10 chains in this case) the operator begins to work the unthinned leave strip to his left and selectively thins up to where the next strip will begin (70 feet in this study). The trees removed from the selectively thinned area are bunched in the previously cut strip. This procedure minimizes damage to the residual stand and also concentrates all of the cut material either in the cut strip or adjacent to it. After finishing the selective thinning in the leave strip, the feller buncher operator repeats the process by moving the leave strip distance to the left and begins a new strip, again laying bunches to the right and into the thinned area he just finished cutting. Progressing in this manner, interference between the felling and bunching and the skidding operation is avoided. Since all material is concentrated in or adjacent to a strip, the skidder operator can easily follow the cutting pattern without making skid route decisions.

Production costs

The total 1974 purchase price of the equipment was about $219,000. Hourly operating cost, including depreciation, interest, taxes, licenses, oil, gas, and other miscellaneous costs was $92.61. Wages and overhead for the 5-man crew was an additional $35.25 per hour, making a total hourly operating cost of $127.86 for labor and equipment if all the equipment was operating at the same time. This was never the case because equipment such as spare vans and yard tractor only operated part of the day. An analysis of labor and equipment costs in dollars per ton, excluding stumpage, marking, and site preparation costs, yielded a total production cost of $8.78 per ton of green chips (Table 4). Sixty-two percent of the cost was attributed to the felling, skidding, and chipping, while 30 percent was associated with trucking.

A break-even analysis was made for the entire operation (fig. 3). The fixed thinning cost was $593 per day to cover labor, depreciation, interest, insurance, taxes, licenses, plus other miscellaneous fixed costs. The hourly equipment operating cost was $36.77. Using the average productivity of 17 tons per hour and an actual revenue at the time of the study of $11.85 per green ton of chips delivered to the mill, break-even was reached after approximately 3-1/2 hours of operation. The break-even chart clearly justifies working a full 8-hour day to maximize profits.

The tabulation on page 18 reflects total stump-to-mill jobber costs which include both nonproduction and production costs. These costs, which do not include a margin for profit, represent 1974 study costs plus estimated 1977 costs.

In 1974 dollars with a jobber cost of $9.60 per delivered green ton and an actual revenue of $11.85 per green ton, the profit margin was $2.25 per green ton. The per acre profit using the average yield of 44.9 green tons per acre for strip with selective thinning was $125.78. Compare this to the direct cost of selective chain saw thinning on the control plot of $33.52 per acre with no product recovery.

Damage

Since northern hardwoods are very susceptible to decay, it is essential that the residual trees are not so severely injured that they will become worthless. Therefore, apparent stand damage was recorded (2).

Mechanized thinning injuries occurred more frequently than in previously reported chain saw thinning studies. However, it is expected that most injuries are relatively minor. Many of the damaged trees can be removed at the time of thinning or in future thinnings and according to previous studies, before significant volume or value losses occur in these young, vigorous stands (8). Many of the damaged trees occurred adjacent to the strips and on the pivot trees where the strip meets the woods haul road. Conceivably, high residual stumps could be left as bumpers for future thinnings. As operators become more proficient at mechanized thinning and as systems improve, tree injuries will lessen.

Two full growing seasons after harvesting, the site was re-examined for

	Thinning costs, dollars per green ton	
	1974 case study	1977 estimated
PRODUCTION		
Harvest	6.18	7.42
Transport	2.60	3.12
NONPRODUCTION		
Stumpage	.50	.60
Marking	.10	.12
Roads and landings	.22	.26
TOTAL	9.60	11.52

early effects of logging damage on regeneration and individual tree growth. Although the area had been extremely dry both growing seasons, which likely had some adverse effect on regeneration and establishment of seedlings, sprout growth was unaffected. Seedlings of all species were not as abundant as expected but seed production was felt sufficient to regenerate desirable tree species. The presence of stump sprouts may present future problems.

Trunks of trees that had suffered bark wounds showed callous growth developing. Many showed vertical spread from the initial wound under the bark and deeper wood discoloration than expected. However, it appears too early to conclusively evaluate wound severity.

Growth

Individual tree growth after two years was checked (Table 5). Overall, northern red oak grew best (one tree grew 1.1 inches), followed by black cherry, red maple, sugar maple, yellow birch, and hemlock. Although not conclusive because of small sample size and observations from only two growing seasons, shelterwood appeared to have the most overall diameter growth, followed by strip with selection, selection only, and strip only. Despite the unusually dry conditions for two seasons, the stand appears healthy and responding to thinning. The shelterwood site as it existed in August 1977, three growing seasons after harvesting, looks pleasing (fig. 1D). Fertilization of thinned stands during or after mechanical thinning may increase growth (13).

Topwood Recovery

Hardwood Residues Case Study

To establish the potential for recovery of tops and limbs, an assessment of these residues was made following commercial improvement cuts on a northern timber sale (9). Measurements on 1-acre circular plots revealed that close to half of the above-ground portion of the hardwood trees was left in the woods following logging--tops and limbs amounted to 41 percent for sawtimber trees and 49 percent for poletimber trees.

Other residues, such as cull sections, unmerchantable trees felled for stand improvement but left behind in their entirety, and trees knocked over or broken during logging, were also categorized by size and weight. Approximately 85 percent of the total residues found were attributed to sawtimber and poletimber; the remainder was in knocked-over or no-product trees (fig. 4A). Considering material only 3 inches in diameter and larger, the combined sawtimber and poletimber categories accounted for 80 percent of the plot residues (fig. 4B). Approximately 55 percent of the top and limb residue in both sawtimber and poletimber trees was greater than 3 inches in diameter (fig. 4C, 4D). The total of all residue classes was close to 18 green tons per acre. About 10 green tons per acre of material was greater than 3 inches in diameter.

Top and limb residue in sawtimber trees amounted to almost 47 green pounds for every cubic foot of product removed and close to 65 pounds of residue per cubic foot of product removed in poletimber. The average green weight per tree in tops and limbs was about 1500 pounds in sawtimber and 480 pounds in poletimber. A separate study related the residue weight for sugar maple sawtimber trees over a range of tree diameters (fig. 5) (12).

It appears too costly to post-log to recover only the straight shortwood sections by cutting and gathering at the stump and then forwarding. Recovery of entire tops with limbs intact is a possible approach but may likely be unacceptable because of root and bole damage to the residual stand (3,11). This damage may be especially severe if recovery is during the summer months when bark is loose. Damage may be significantly less if recovery of entire tops is during the dormant months when bark is tight.

Testing of a Prototype Topwood Harvester

Forest engineering research in the North Central States has developed a unique concept to recover tops and limbs from hardwood sawlog operations. The concept developed is to render large hardwood tops (fig. 6A) into a compacted form

more suitable for grapple skidding (fig. 6B). To prepare tops in this fashion, an experimental topwood harvester employing a small, highly maneuverable, hydraulically actuated shear was designed and specially mounted on a knuckle boom of a carrier vehicle. The specially designed mounting device is a principal feature because the shear assembly can be rotated to practically any orientation. This maneuverability makes it possible to sever the large protruding limbs and align them with the butt of the main stem of the top. Once all large limbs are severed and aligned, the compacted top is ready for forwarding to a woods landing.

The study objectives were to: 1) evaluate a completely mechanized system for recovering hardwood tops and limbs (fig. 7); 2) test the capabilities of the prototype topwood harvester; 3) evaluate residual stand damage; and 4) determine production volumes and costs associated with topwood harvesting in a selectively logged northern hardwood forest.

At the time of this writing, the topwood harvesting study is in the final stages of completion. Therefore, all data and results presented are preliminary. Future publications will report the final study results and data in detail.

The study area contained 21 acres and is located at Michigan Technological University's Ford Forestry Center about 10 miles south of L'Anse, Michigan. A pre-harvest inventory indicated a volume of 7 thousand board feet (Net Scribner) and 6 cords of hardwood per acre. The soil is a well drained, coarse, gravelly loam. The tract is on level terrain traversed by an all weather road. Previous selective logging was conducted in 1938 and 1967. The 1977 estimated harvest is 1800 board feet and 5 tons of hardwood pulpwood per acre. Although very little topwood volume was utilized during the conventional sawlog harvest, 107 tons of hardwood pulpwood was later removed from the residual tops before recovery of tops. Had that portion been left with the original tops, an additional 5.1 tons per acre would have been recovered during topwood removal, thus making the economics of topwood recovery more attractive. This especially applies to the well managed test stand--sawlog volumes were high and topwood volumes low (Table 6).

The prototype shear assembly was capable of severing and bunching hardwood limbs up to 12 inches in diameter. The carrier vehicle, a Gafner 4000 series mini-skidder, had a rear-mounted boom to which the shear was attached by a highly flexible coupling mechanism (fig. 8). The skidder was specially outfitted with a sophisticated remote control hydraulic system which incorporated all operational functions into two "joystick" control devices plus one foot pedal. With operator experience, this control system should allow fast and efficient operation. The prime mover was not selected on the basis that it was an ideal machine, but because of its availability.[2] This experimental harvester was used to cut and bunch only large tops. The operator skipped small tops not having large protruding limbs. It was felt the small tops would not create objectionable residual stand damage during forwarding.

Following cutting and bunching, the tops were skidded by a Clark Ranger 667GS grapple skidder to a Morbark Model 22 Whole Tree Chipper (fig. 7). All recovered tops were chipped and blown into two large piles, one of which had estimated cubic foot top volumes for all chipped tops in that pile. It was this pile that was weighted. A chain saw operator was located at the landing to sever any remaining large limbs which still hindered the chipping operation. The number of chain saw cuts were recorded. A detailed time study was conducted on topwood processing, skidding and chipping operations to establish performance and operating costs.

Results of Topwood Harvesting

The prototype topwood harvester was used to cut and bunch 115 tops (table 7, fig 9). Additionally, 40 tops were passed over by the operator because it was felt they were too small to require processing. Of the 115 processed tops, the extent of processing ranged from bunching only (no cuts) to a maximum of 7 cuts per top with a mean of 2.3 cuts per top. If all 155 tops were considered as processed, the average cuts per top are reduced to 1.7. Diameters of cut limbs ranged from 2 to 11 inches with an average of 6.3 inches (fig. 10). The average time to process the tops was about 4 minutes without delay and slightly under 6 minutes per top with delays (table 8).

The topwood harvester delays include: 1) unavoidable delays, such as operator decision-making prior to processing, cutting saplings which impeded topwood processing, and repositioning of moving limbs to improve accessibility to complete a top; 2) mechanical delays although normally included in the production figures as unavoidable, were listed separately because "prototype debugging" delays would normally be eliminated in a production machine--these delays typically

[2]Memorandum of understanding between Gafner Machine, Inc. and North Central Forest Experiment Station, USDA, April 30, 1976.

Table 6. -- TOPWOOD HARVESTING PRODUCT INFORMATION

	Study plot averages	Per acre
Number of sawlogs removed	--	20.6
Gross board feet removed (Scribner)	--	2,087
Net Board Feet removed (Scribner)	--	1,924
D.b.h. of trees (inches)	17.7	--
Height of trees (feet)	76	--
Crown width (feet)	23	--
Crown length (feet)	37	--
Diameter of butt end of residual top (in.)	12.1	--
Top weight (tons)	.7	7.33
Hardwood pulpwood removed[1/] (tons)	--	5.1
Total tops[2/]	--	14.5

1/ Pulpwood was removed prior to topwood recovery.

2/ Includes processed, unprocessed and tops not recovered (lost in deep snow).

Table 7 -- SUMMARY OF TOPWOOD HARVESTER DATA

	Processed	Skipped
Total tops	115	40
D.b.h. of trees (inches)	18.7	13.2
Height of trees (feet)	79	68
Top width (feet)	27	17
Top length (feet)	37	37
D.o.b. of butt end (inches)	13.4	9.1
Relative volume[1/]	3	1

1/ Relative volume of processed was approximately three times greater than the unprocessed tops.

Table 8. -- BREAKDOWN OF AVERAGE PROCESSING TIME PER TOP (minutes)

Time per top (without delay--100% utilization)	4.1
Unavoidable delay	.2
Mechanical problems	.8
Avoidable delay	.6
Total time per top	5.7

included problems with the controls, shear blades, and oil leaks from loose or poorly protected fittings; and 3) avoidable delays related to the prime mover, such as lifting and lowering stabilizer pads and climbing in and out of the two seats which was required for operation of this particular machine. A more desirable machine would eliminate these delays. Lunch and breaks are not included in the reported delays.

Since all of the chips have not been hauled and weighed at the time of this writing, the data reported are based on a preliminary study estimate of 0.7 green tons per top. These data may require future moderate adjustments after all recovered chips are weighed and correlated to number of tops.

Topwood harvester productivity was only 10.2 tons per hour (without delays), whereas the number of tops processed to produce this amount was quite high at 14.6 (table 9). Previous studies (9) have shown that in similar stands where prior product utilization was not so high, nearly half of the weight of harvested trees was left in the woods. If the 107 tons of pulpwood were not removed prior to topwood recovery, the topwood harvester would have processed about 15.3 tons per hour.

Excluding all delays, the topwood processing cost was $2.25 per green ton ($1.58 per top) (table 9). Had the average 5.1 tons of previously recovered pulpwood been left with the original tops, the estimated costs associated with cutting and bunching would decrease from $2.25 to $1.51 per green ton.

The above figures include no delays. A 20 percent decrease in productivity resulted when including only the unavoidable delays defined earlier. Also, productivity is expected to increase as the operator develops more skill and confidence in processing tops in this manner and becomes more familiar with the "joystick" control system. A general observation was that the operator should process the tops much more aggressively, and mentally plan his processing approach before proceeding. In this study the operator lost time due to "wrong" decisions in cutting and positioning of limbs.

Skidding costs were higher than anticipated (table 9). Based on a 1700-feet round trip skid distance and average payload of 0.84 tons per grapple load the cost of skidding was $4.38 per green ton (without delays). (Compare this average skid load to the thinning study previously described where 9 to 11 pole-sized whole trees made up a skidder load and ranged in weight from 1.7 to 2.6 green tons.) As suggested earlier, had the sections previously removed as pulpwood been left with the original tops, the estimated skidding costs were calculated to decrease to $2.92 per green ton. Skidding and chipping was done in midwinter under severe conditions. Many tops were nearly completely covered by deep snow and the skidder had difficulty maintaining traction. Some tops were frozen to the ground and needed to be broken free. It is believed that an increase in productivity of at least 10 to 20 percent could have been realized had better conditions existed.

Chipper utilization was very low because only one skidder was used. Actual chipping productivity was less than 5 tons per hour (includes all delays) (table 9). At 100 percent utilization, the chipper productivity was 17.5 green tons per hour which yielded a cost of $2.57 per green ton. The productivity and cost data of table 9 clearly show the need to keep the chipper supplied with material.

There was still a need to sever some limbs or stubs which would not feed into the chipper. Of the 220 tops chipped, 160 of them required at least one chain saw cut. Many of the tops which had been pre-cut by the topwood harvester had short stubs protruding which restricted proper feeding and had to be removed. This function was not time consuming but necessary--the chain saw cost was $.18 per ton. An improved topwood processor design may permit removal of limbs closer to the main stem and eliminate the short stubs. The weakest link in the operation was skidding. The chipper averaged one ton of material in 3.4 minutes compared to skidding the same ton in 8.1 minutes (table 10).

In comparing cost, the topwood harvester was the least expensive, processing at the 100 percent utilization rate of $2.25 per ton. Total harvesting, excluding trucking, amounted to $9.38 per green ton (table 9). This cost is estimated at $6.32 per green ton had the pulpwood been left with the tops as previously suggested.

Following the conventional selective sawlog harvest a post-logging damage assessment was made on several 1/5-acre circular inventory plots. All felling and skidding damage associated with the original selective logging was identified and marked. Following topwood harvesting all new damage was also recorded. At this time, the assessment of damage to the residual stand has not been completed but will be reported on in the final publication describing this research. However, a brief inspection of the residual stand shows relatively minor damage. This was perhaps one benefit of the deep snow which acted as a cushion. Also a benefit was the season of the year; in winter the

bark is tight.

Topwood Recovery Observations and Recommendations

Critical evaluation of this one-of-a-kind study permitted identification of various problems that could be eliminated by better planning of future systems to increase system efficiency.

Most sawtimber operations leave behind large tops from which no pulpwood sticks have been removed. This seems desirable because the main stem of the top can be more easily fed into the chipper throat. This reduces the processing time per top, even though more tonnage is chipped. The feed rolls have difficulty engaging a branch top that has no main stem.

Even though processed tops were more compact, they were still difficult to skid. For the particular skidder used, in some instances it was much easier to skid uncut tops than cut tops because some pieces had a tendency to slip out of the grapple when the load shifted. A skidder with a constant pressure grapple may lessen this problem. A grapple skidder with a cable system for tightening the grapple load seems a better choice. Future studies might compare choker skidding with grapple skidding including the combination of grapple with internal cable.

When skidding small tops (such as those in this study which averaged about 0.7 tons per top) two small skidders with a payload capacity of about 1 ton may be a better choice (skidding with a single skidder limits productivity).

For this study, a chainsaw operator was stationed at the chipper at all times to make any necessary cuts on the tops so they could be chipped. Since this operator was utilized only 12.5 percent of the time, it might have been just as effective to have the chipper operator do his own chainsaw work. Or, another approach is to replace the conventional chipper grapple with the type of grapple design which incorporates a hydraulically actuated chainsaw built within the grapple and controlled by the chipper operator.

The chipper used in the study had a grapple with large teeth welded to its outer edges. This enabled the operator to place the closed grapple within limb junctures, and upon opening, the grapple would split the two limbs. This innovative grapple modification functioned very well for this purpose.

With time study data obtained from this study, plus use of an existing topwood harvesting computer simulation model, various alternatives will be tried on the computer, including more realistic skid distances.

Development of a Spiral-head Chipper

The "Fingerling" Concept

An early concept developed at the Forest Products Laboratory, Madison, Wisconsin, formed the basic guidelines of what intermediate product form forest residues should be reduced to (6)(7). This idealized concept was to produce particles of elongated dimensions in the fiber direction--approximately 2-1/2 to 3-inches long with a nominal cross-section of 1-inch by 1-inch. These idealized particles, termed "fingerlings," would then be ring flaked to a thickness of approximately 0.015 to 0.02 inch. These long, thin flakes were believed to be ideal for producing either an aligned or randomly oriented flakeboard. The flake aligned boards would have superior strength properties in the direction of alignment. The aligned flakeboards would then be alternately layered, as veneer sheets are in plywood, to produce an engineered flakeboard having desired strength properties and characteristics.

The task assigned to the Forest Engineering Laboratory in Houghton, Michigan, was to develop a concept for a woods-portable machine which would render small-sized forest residues into "fingerling" particles (fig. 11). In-woods fingerling production was deemed essential because of the high cost and problems associated with handling and transporting small diameter and crooked residue materials. The more homogeneous fingerlings are much easier to handle and transport in bulk.

The failure of conventional chippers to produce particles having the desired fingerling geometry make them unsuitable. Also, a review of current wood cutting mechanisms did not reveal how the idealized fingerling particles could be produced. It was therefore apparent that a completely new chipping concept was needed. The resultant mechanism was a very novel spiral screw-type cutterhead mounted on a rotary shaft. A simple laboratory machine, which we appropriately called a spiral- or helical-head chipper, was designed, built, and tested (fig. 12). (4)(5). This novel, spiral-head chipper is available for non-exclusive licensing from the U.S. Government (1).

Testing of the Spiral-Head Chipper

The prototype spiral-head chipper was laboratory tested for fingerling particle production from several different small diameter Lake States and Intermountain species. The experimental machine was designed to chip material to about 5 inches in diameter. Evaluations included overall cutter performance, power requirements for spiral-head chipping, and size analysis of the resultant particles.
Initial tests revealed this

continuously engaged chipper produced 95 percent or more of the particles to the desired length set by the cutter (fig. 13). However, since many of the cut pieces were much larger than the target 1-inch by 1-inch cross-section, a means was needed to reduce these oversize chunks to the desired fingerling size. This problem was solved by single-pass feeding of the oversize material through a conventional hammermill with all grates removed (fig. 14).

The resultant fingerlings were flaked at the Madison Forest Products Lab in a Model PZ-8 Pallman ring flaker. Even though the fingerlings still had considerable cross-section variability, they did orient themselves in the ring flaker so that the knives cut in a plane parallel to the wood grain. (The performance of ring flakes made from spiral-head chipper fingerlings is discussed in a separate paper on flakeboard furnish.)

The power requirement for spiral-head chipping was determined (table 11) by strain gaging the shaft on which the removable cutter was mounted (fig. 15). Based on prior crosscut shearing and chipping research conducted at the Forest Engineering Laboratory, the power requirements are related to the specific gravity of the wood, and horsepower requirements can be estimated for other species.

Because of the complexity of fabricating the early cutter heads, certain imperfections resulted which likely added to the basic power requirements. In spite of such fabrication imperfections, the power requirements for producing the fingerling particles are not unreasonably high, but certainly higher than producing conventional wood chips. The spiral-head chipper operates without the benefit of a large flywheel, as do conventional disc chippers, and at a much slower speed. Additionally, because of the basic cutter head design, two to three segments of the spiral cutter are engaged in the sample at one time. All these factors add to the frictional forces involved and total power required.

Based on removal of 2-1/2-inch fingerling particles the theoretical rate of production of spiral-head chipping naturally increases with increases in log diameter and cutter head rpm (table 12). Although the laboratory spiral-head chipper was operated at only a nominal 150 rpm, it is expected that production units would operate at a rotary speed two to three times this rate.

Comments on Spiral Cutterhead Fabrication

Since this spiral cutter is unique, methods of fabrication are not established. Several cutters were made with each subsequent cutter showing improved quality and ease of fabrication. To withstand the cutting forces the spiral cutting head must be made with an alloy steel that can be hardened to at least 45 Rockwell C. Although several steel types are suitable, our first spiral cutter was made with boralloy (Paper Calmenson & Co., St. Paul, MN) which gave adequate hardness. However, heat treating and postwelding exaggerated the original plate warpage when the spiral flights were formed. Later cutters were designed with the original plate stock surface ground, welded to a removable sleeve with preheating, and the entire assembly heat treated to the required hardness. This procedure reduced warpage.

Our original spiral cutter was mounted on the shaft by progressively tack welding with the aid of pre-cut spacers of fingerling length. Each spacer was progressively longer than the previous one so as to produce a cutter having a continuously increasing pitch starting from the front of the cutter head. Failure to provide increasing pitch causes the fingerlings to pack in the flights until later cuts eventually force them out. Flight packing is undesirable since it increases friction thereby increasing horsepower requirements. Ideally, the particles are cleared as soon as they are severed.

After only limited operation of the spiral-head cutter with the blade tack welded, failure resulted. Following spot weld failure, the blades were then continuously welded to the shaft which caused excessive warpage. Although the continuous weld resulted in longer cutter-head life, even they eventually failed and needed to be spot repaired.

Although suitable for a laboratory machine, it was recognized that for a woods-portable machine it would not be practical to mount the blade permanently to the drive shaft. Thus, a more practical cutter head design resulted which had the spiral blade mounted on a removable collar. The collar was fabricated with a spiral slot less than the collar thickness, and the blade mounted by essentially screwing it onto the collar and then tack welded. This produced a much better quality cutter head but is still not the ultimate answer to spiral-head chipper fabrication.

A second prototype spiral-head chipper is now being designed which will include an improved spiral cutter that is easier to fabricate and mount. Additionally, the new design will include a means to remove by force the severed particles as they are formed. A low-friction anvil will be incorporated into the design to reduce power requirements. Cutter speed will be increased over the initial prototype as well as diameter of material to be chipped. Future plans are

Table 9. — PRODUCTIVITY AND COSTS FOR HARVESTING OF HARDWOOD SAWLOG TOPS AND LIMBS

Equipment	Productivity		Study Costs	Ext. Costs[7]
	Tops/hour	Green tons/hour	$/green ton	$/green ton
Topwood Processor[1]	14.6[5] (10.5)[6]	10.2 (7.4)	2.25 (3.11)	1.51 (2.09)
Skidder[2,3]	8.9 (6.7)	6.3 (4.8)	4.38 (5.74)	2.92 (3.83)
Chipper[4]	25.0 (6.1)	17.5 (4.3)	2.57(10.46)	1.71 (7.01)
Chainsaw	--	--	0.18	0.18
Total			9.38	6.32

[1]Assumed topwood harvester cost of $45,000 ($23.04/hr.)

[2]Skidder cost of $65,000 ($27.57/hr.)

[3]Based on average skid distance (round trip) of 1700 feet (830 feet in-woods and 870 feet on skid road).

[4]Chipper cost of $133,000 ($44.98/hr.)

[5]At 100% utilization

[6]Includes all delays

[7]Estimated costs data assumes previously recovered pulpwood are recovered with the topwood.

Table 10. -- TOPWOOD PROCESSING TIMES

(minutes/ton)

	No delays	With all delays
Topwood harvester	5.9	8.1
Skidder	8.1	10.6
Chipper	3.4	14.0

Table 11 — POWER REQUIREMENTS FOR PRODUCING FINGERLING CHIPS WITH THE U.S. FOREST SERVICE SPIRAL-HEAD CHIPPER

Species	Samples (number)	Range (spec.gr.)	Specific Power (HP-min/FC^3)
Aspen	8	0.343 - 0.377	5.2
Basswood	7	0.278 - 0.318	5.2
Douglas-fir	1	-	8.1
Lodgepole pine	12	0.413 - 0.466	8.7
Larch	8	0.492 - 0.515	9.2
Red oak	6	0.510 - 0.549	9.3
White birch	14	-	9.6
Red maple	5	-	9.8
Sugar maple	3	0.618 - 0.658	15.1

Table 12 – FINGERLING PRODUCTION BY OPERATING SPEED AND LOG DIAMETER

Log Diameter	Cutter Head RPM 300	350	400
(Inch)		(Cubic Feet/Min)	
4	5.5	6.5	7.5
6	12.0	14.0	16.0
8	21.5	25.0	28.5
10	34.0	40.0	46.0

to have this improved design built and tested.

Summary and Conclusions

Two primary sources of underutilized North Central States forest resources have the potential to provide substantial amounts of fiber for structural flakeboard: thinning from northern hardwoods and sawlog tops and limbs. By conventional practices, both are normally left in the woods to rot. These wasteful practices and unsightly residues must be eliminated. The traditional reason for leaving this material behind has been the questionable economics related to harvest and transport of thinnings plus tops and limbs.

Forest Engineering Research at Houghton, Michigan, has demonstrated that mechanized thinning of pole-sized northern hardwood can be an effective means of timber stand improvement and permit recovery of the thinned products at a profit. Test trials with mechanized thinning recovered approximately 50 green tons per acre of whole-tree chips at a profit margin of $125 per acre. Conventional chainsaw thinning in Michigan typically costs $25 to $35 per acre and the felled trees are left on the forest floor to rot.

Case studies in residue assessment of hardwood sawlog tops and limbs revealed that about half of the tree is left in the woods after sawlog removal. About 55 percent is greater than 3 inches in diameter. Total residue (all sizes) amounted to an average of 18 green tons per acre. Material greater than 3 inches in diameter was about 10 green tons per acre.

Massive hardwood sawlog tops, if forwarded from stump to landing intact, would likely cause excessive damage to the residual stand--especially during the growing season. A concept developed by the Houghton laboratory is to snip the large protruding limbs with a highly maneuverable, hydraulically-actuated shear, and then align the severed limbs with the main stem of the top. Although results are preliminary, testing of a prototype topwood processor to prepare large tops in compacted form for grapple skidding to woods landing has shown considerable promise.

Residue tops from a conventional selective sawlog harvest were harvested for slightly under $9.50 per green ton converted to conventional chips, excluding transportation. It is expected that as equipment and techniques--including operator skill--are improved, topwood recovery will become economically more attractive.

Because of existing markets, the system discussed for recovering hardwood thinnings and topwood include converting the product to conventional pulpwood chips. However, conventional chips are unsuitable for structural flakeboard because of the inferior flakes produced from chips. A novel spiral-head chipper has been developed and laboratory tested to reduce small diameter residues to "fingerling" particles that are much more suitable for ring flaking. This Forest Service patented development is available for non-exclusive licensing.

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Figure 1. (A) Typical northern hardwood poletimber stand.
(B) Logging residues following conventional chain saw thinning.
(C) Thinning with a mechanical feller buncher with accumulating head.
(D) Poletimber stand after mechanized shelterwood thinning.

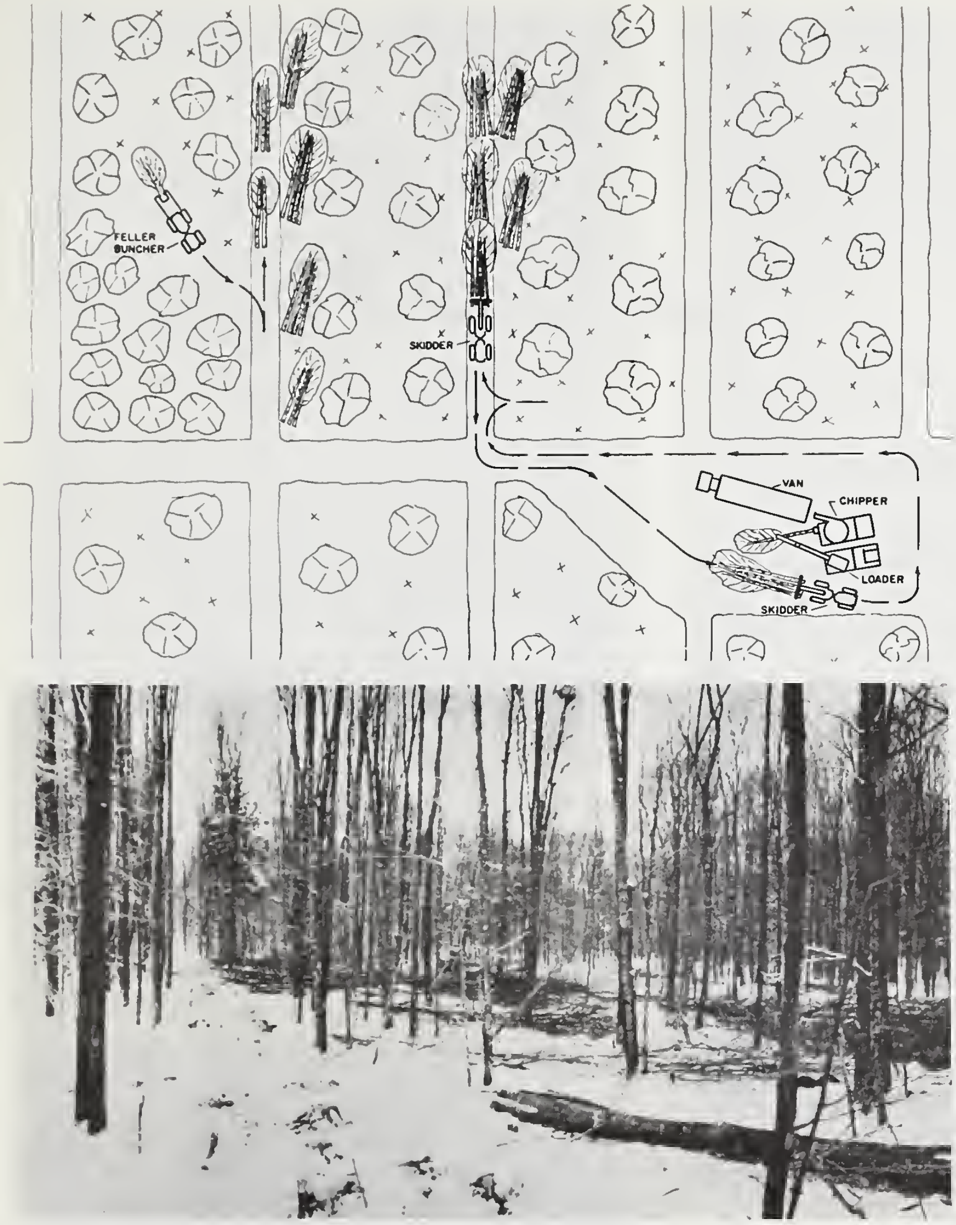

Figure 2. Strip with selective thinning in leave strip
(A) Simplified schematic of system.
(B) Pre-bunched trees ready for grapple skidding.

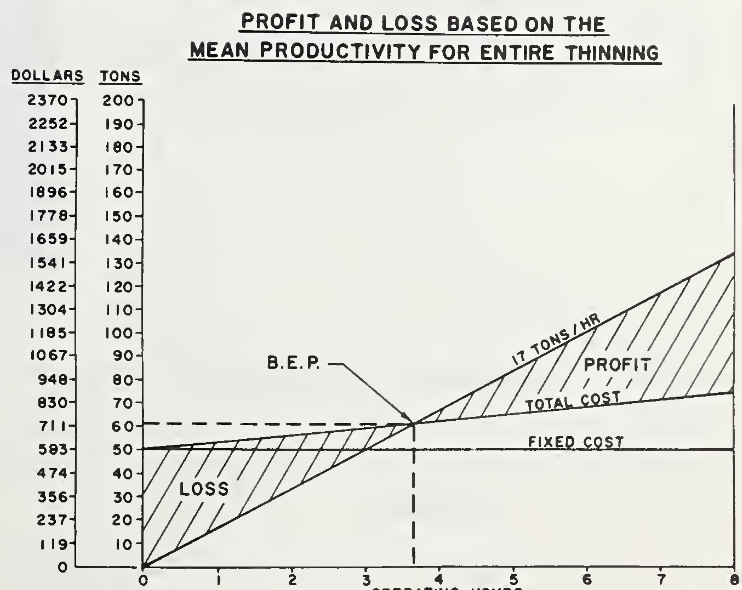

Figure 3. Break-even analysis of mechanized thinning. (2)

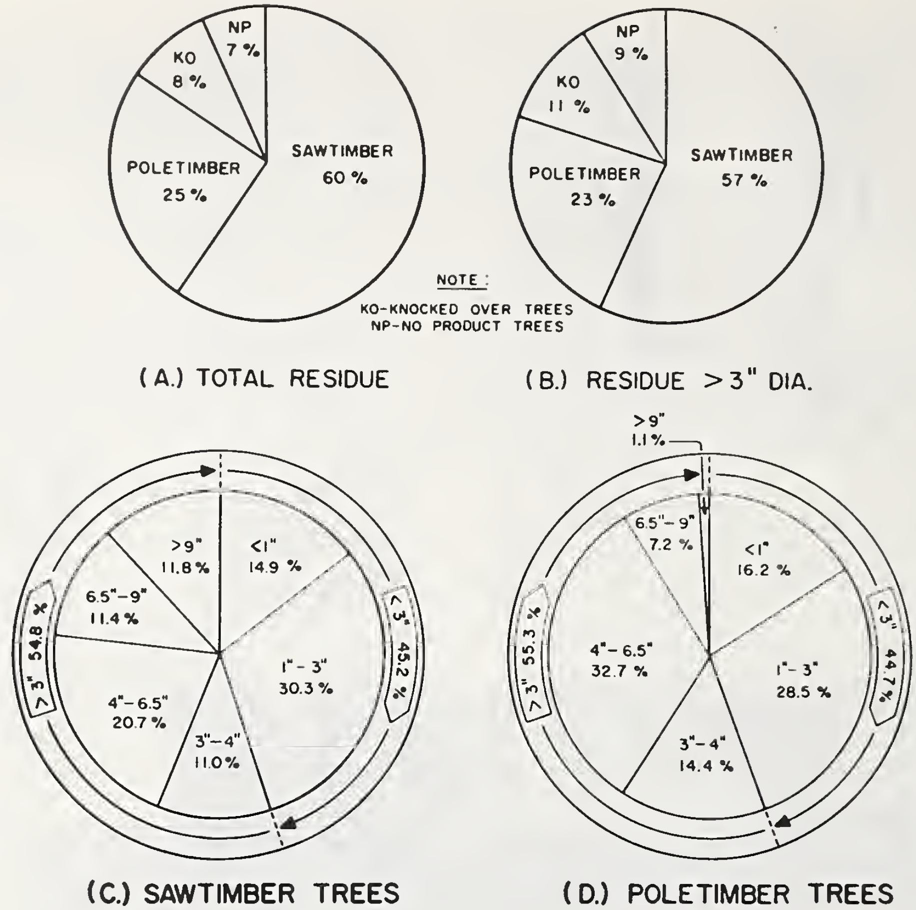

Figure 4. Source and size breakdown of residual tops and limbs following a northern hardwood sawlog timber sale. (9)

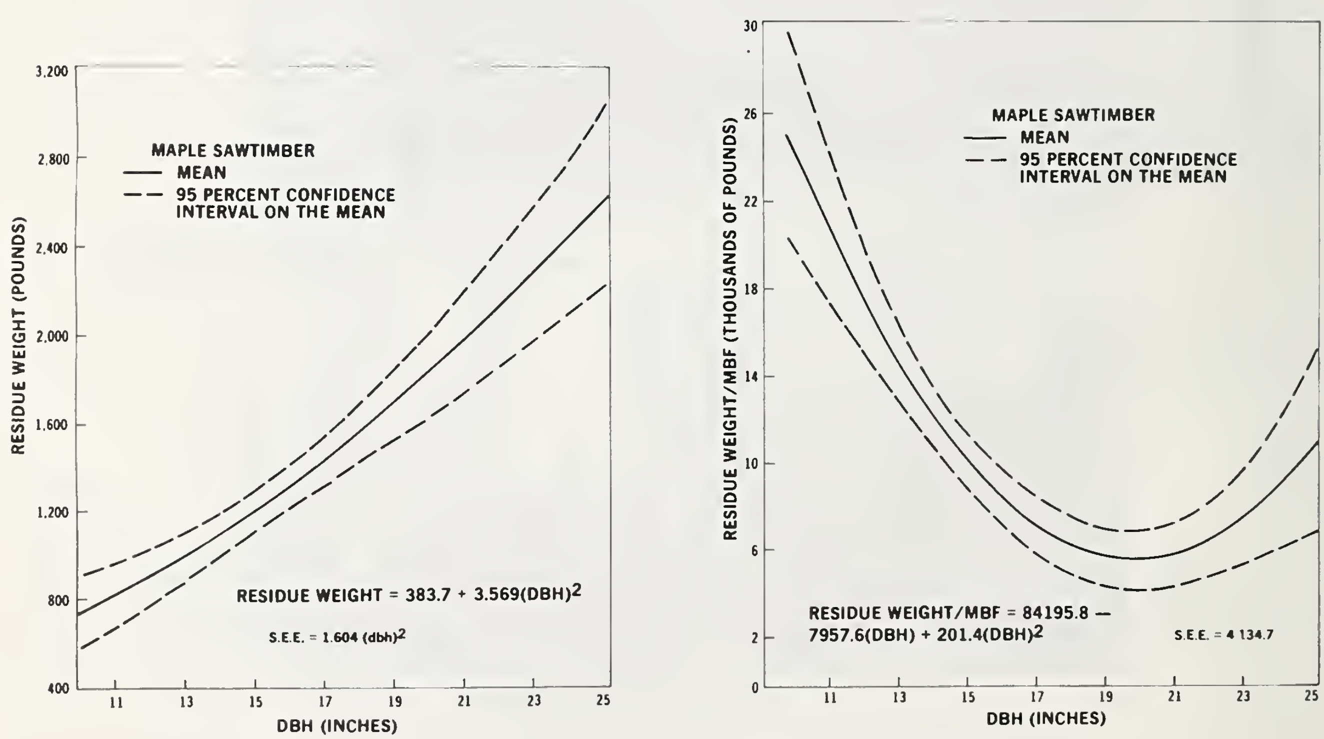

Figure 5. Variation of residue in sugar maple sawtimber trees. (12)

Figure 6. In-woods preparation of hardwood sawtimber tops for forwarding. (A) Typical hardwood sawlog top. (B) Compacted top.

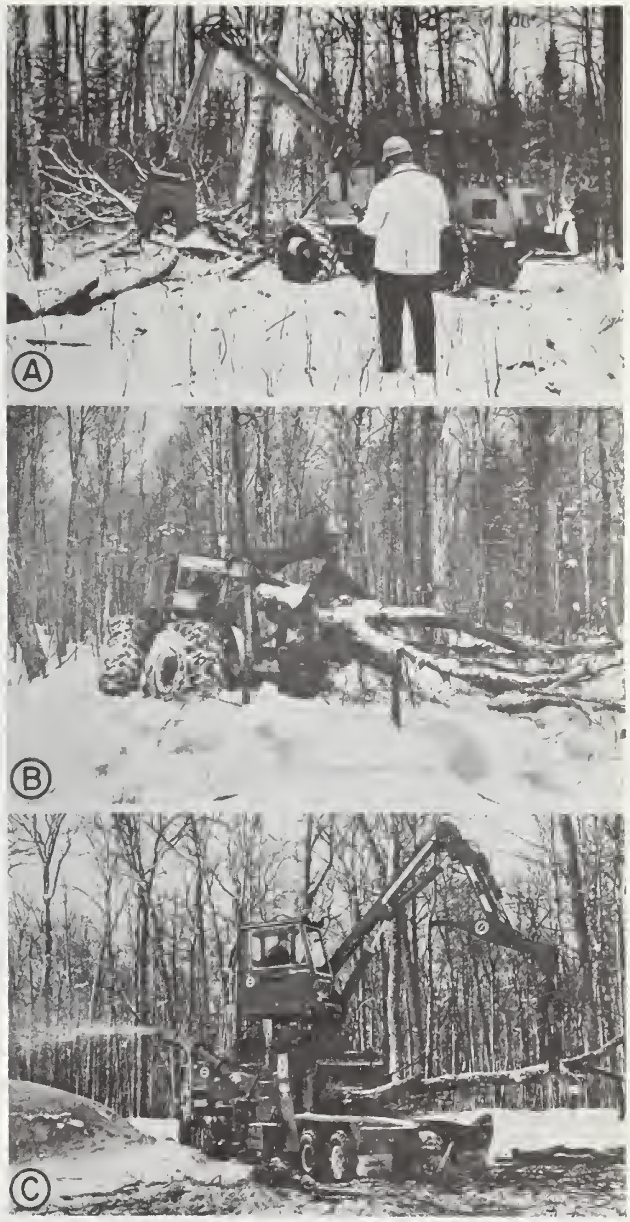

Figure 7. Field trials with mechanized topwood recovery. (A) Experimental topwood processor. (B) Grapple skidding of processed top. (C) Conventional chipping of recovered topwood.

Figure 8. Experimental topwood harvester processing a sawlog top.

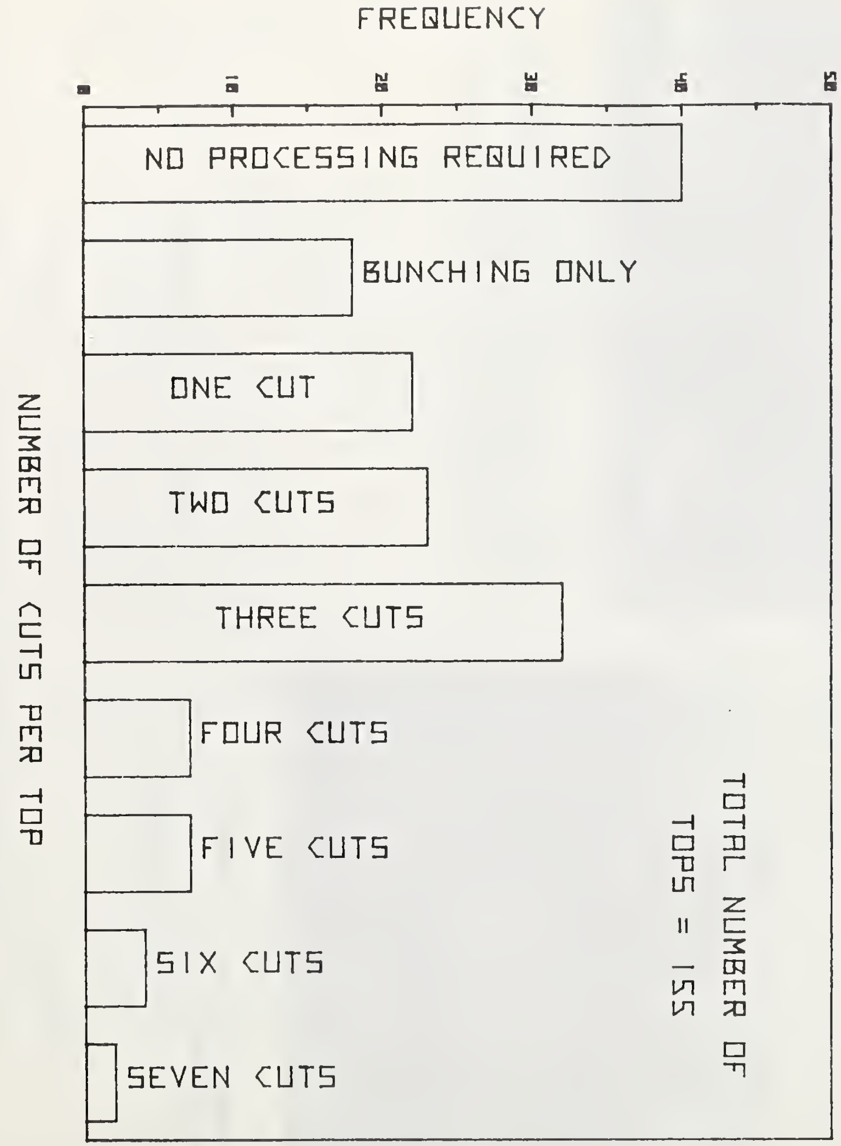

Figure 9. Summary of topwood processing data--number of limbs severed per top.

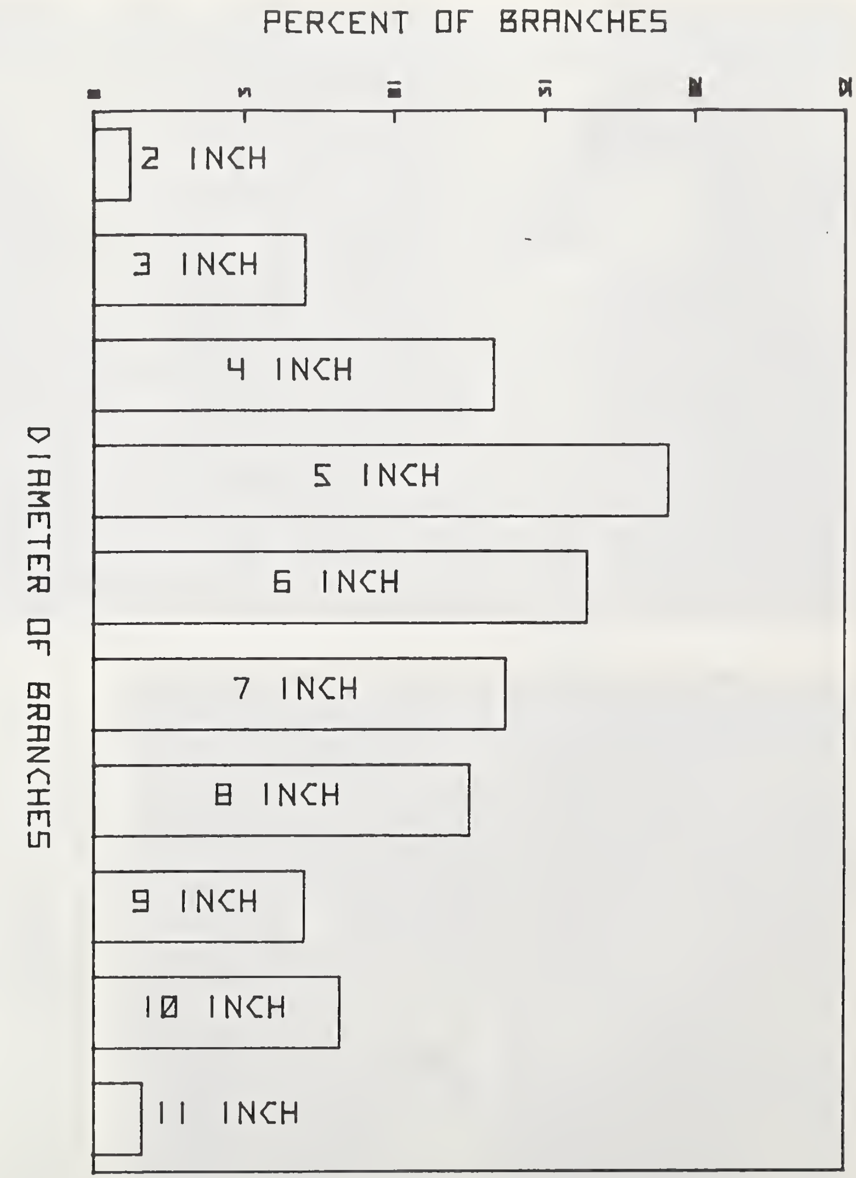

Figure 10. Summary of topwood processing data--size of limbs severed.

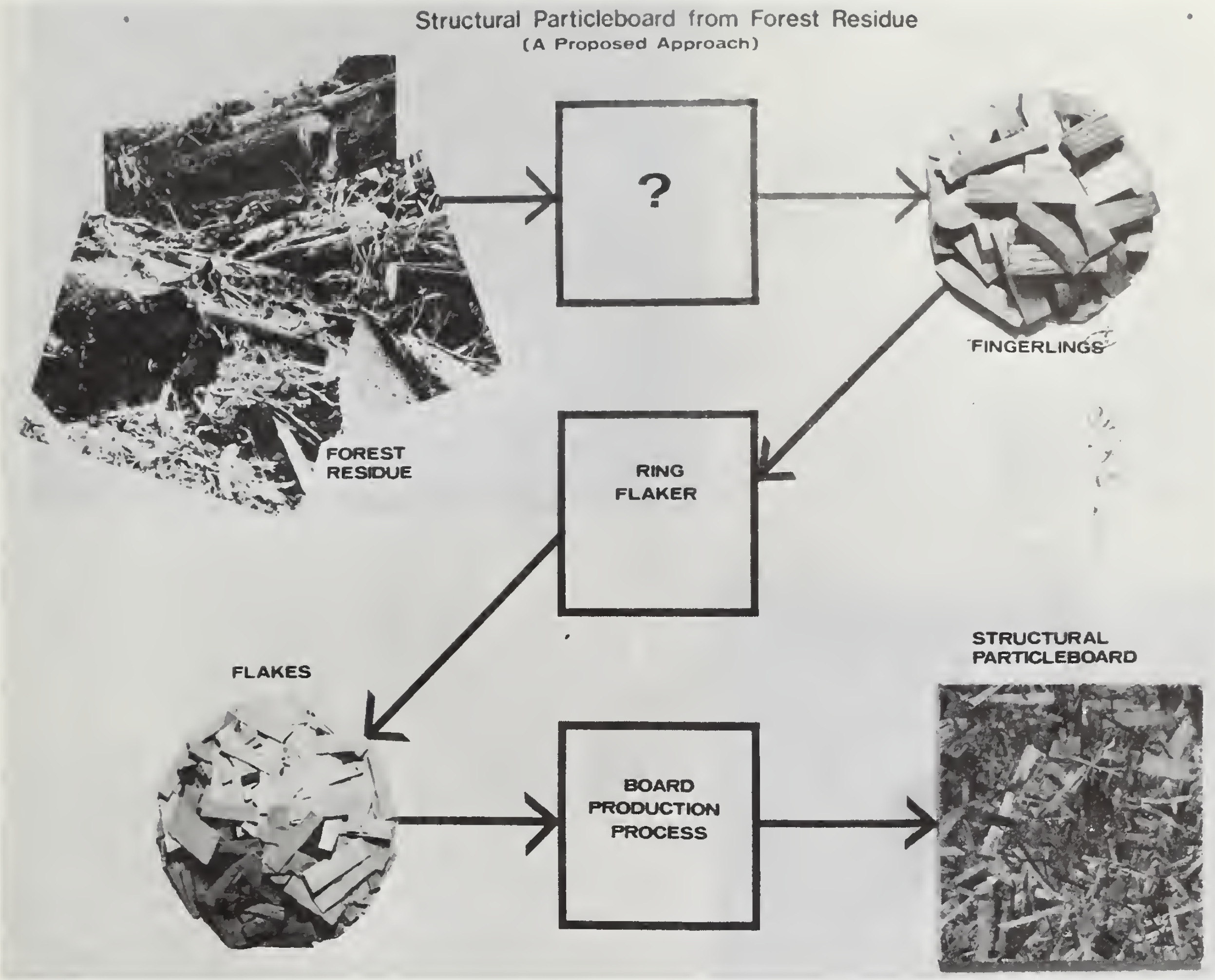

Figure 11. "Fingerling" approach to using forest residues in structural flakeboard.

Figure 12. Laboratory testing of experimental spiral-head chipper.

Figure 13. Screened red maple particles cut with spiral-head chipper.

Figure 14. Reduction of oversized spiral-head chipper particles to fingerlings by subsequent hammermilling.

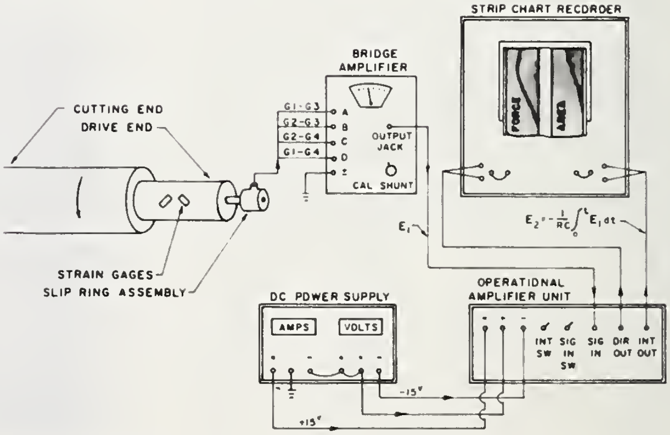

Figure 15. Schematic of instrumentation to determine power requirements to produce fingerling chips with the U.S. Forest Service spiral-head chipper.

STRUCTURAL FLAKEBOARD: COLLECTION, TRANSPORTATION, AND PREPARATION OF WESTERN FOREST RESIDUES

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Abstract

Despite sporadic attempts at utilization, huge quantities of forest residues remain unused in the western United States. Structural grade flakeboard has been experimentally manufactured from residues, but costs, particularly the harvesting and processing of residues, render the product noncompetitive with plywood. Improved harvesting and processing equipment may soon improve the economic feasibility of converting residues to structural flakeboard.

KEY WORDS: forest residues, pulp chips, particleboard, inwoods chipping, costs.

Introduction

In the western United States, forest residue is defined as wood left on an area after logging, thinning, road building or clearing operations and fire, disease, and insect killed timber. This includes tops, unmerchantable trees, broken pieces, and dead or defective logs. The residue generated on a particular area by forestry activities can be affected by the terrain, site, vegetative type, aspect, species, harvesting system, equipment, and the sales agreement. The quantity of residue can affect the economics of utilizing this material.

Because of the newness of the concept, very little work has been done on forest residues as a raw material for structural flakeboard. Research studies have been made on their use for pulp and paper manufacture, conventional particleboard, and as a fuel source. It is assumed that much of the information developed in these studies would be transferable to a structural flakeboard industry. Table 1 shows that there is an abundant supply of forest residues on the large National Forest acreage in the West. The cost of collecting, transporting, and processing this material has been the major constraint on its utilization.

Although, at the present time, disposing of forest residue is a problem, the potential structural flakeboard manufacturer should know that other segments of the forest products industry have used or have looked at the possibilities of utilizing all or portions of this waste. During the pulp chip shortage of 1973 and 1974, many paper companies chipped forest residues. Also, public and private research facilities have studied the use of residues as fuel and as a potential source of chemicals. All of these uses appear uneconomical under present conditions. However, as equipment manufacturers develop new processing machinery, the use of forest residues will undoubtedly increase.

This report reviews the status of forest residues in the western United States--quantities available, attempts at intensive utilization, harvesting and processing equipment and costs, and potential products. Although other uses are not ruled out, feasibility of converting residues to structural grade flakeboard received special emphasis. For convenience the West has been divided into three areas and each area is discussed separately.

Southern Rocky Mountains

In 1974, Sampson and others, published an evaluation of inwoods chipping in the Four Corners area comprised of Arizona, New Mexico, Colorado, and Utah. The objective of this study was to determine the possibility of producing pulp chips from unmerchantable trees and from residues usually left in the woods. The study trees, mainly ponderosa pine, Engelmann spruce, Douglas-fir, and white fir were felled, limbed, and bucked with chain saws and skidded with rubber-tired or tracked skidders. A Nicholson Logger Model Utilizer[2] was used to debark and chip the material at the landing. The pulp chips were blown into a chip van for transport to either a reload station or to a pulp mill.

The results of this evaluation showed that timber utilization was improved (the minimum diameter processed through the debarker was 3 inches), the environmental

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[1]Stationed at the Intermountain Station's Forestry Sciences Laboratory in Missoula, Montana.

[2]Use of trade names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

Table 1. — ACREAGE CUTOVER, VOLUME HARVESTED, AND QUANTITY OF RESIDUE GENERATED ANNUALLY ON NATIONAL FORESTS IN THE WESTERN REGIONS[a]

Region	States	Estimated annual harvest		
		Acreage	Volume	Residues
			(MM Bd. Ft.)	(M tons)
1	N. Idaho Montana	110,000	1,200.0	5,500.0
2	Colorado Wyoming South Dakota	74,000	315.0	750.0
3	Arizona New Mexico	209,191	401.5	1,000.0
4	Nevada Utah S. Idaho	53,000	437.0	1,800.0
5	California	150,000	1,900.0	15,000.0
6	Oregon Washington	600,000	4,500.0	24,000.0

[a]Personal communication with timber management and fire control personnel in the various regional offices.

quality of the harvested areas was not impaired, and that high-quality chips were produced. Unit cost of producing chips in the woods were substantially greater than for chips produced at a mill.

The total cost of producing chips by this procedure was estimated to range from $25 to $30 per ovendry ton. Transportation costs increased these values to $42 to $60. The report stated that these costs would probably decrease as the operating crew became more proficient and as the equipment was modified to better conform to the field conditions.

Northern Rocky Mountains

During the pulp chip shortage of 1973, a commercial operator in north Idaho used 2 Melroe Bobcat feller-bunchers, 2 Timberjack 360 grapple skidders, and a Morbank 75 chipper to clearcut lodgepole pine stands on Federal lands and partially cut mixed stands on State lands. This was a multiproduct operation in that stud logs were also obtained. The average diameter of the trees removed was 5.5 to 6.0 inches d.b.h. and the volume removed, 20 to 25 cords per acre.

The procedure followed was to fell and skid about three days in advance of chipping. The feller-bunchers sorted the trees when felled. Smaller trees were bunched for skidding to one landing and the larger trees, from which saw logs or stud logs could be cut, were bunched for skidding to a second landing located a short distance from the first. After the logs had been cut and decked, the tops were pulled to the first landing.

All the material accumulated at the first landing was chipped without debarking. The stem-wood chips were blown into a van for transportion to a mill and the branch and foliage chips were blown into a separate pile for disposal either by burning or by spreading over the harvested area.

This system proved to be most efficient. Approximately 1,000 stems per shift were cut and skidded about 660 feet. Chip production averaged 8 to 10 loads of 11 to 12 units per trailer each shift.

The pulp mill receiving these chips reported no processing problems, although as the chip supply from mill refuse became more abundant, the pulp mill required chip screening and bark removal. The delivered price for these chips was about $33 per ovendry ton.

A major forest products company in the Northern Rocky Mountains has also investigated the possibility of utilizing forest residues for pulp chips and as fuel. In one study, an old-growth stand was clearcut and a mixed-age stand was partially cut. Production in ovendry tons per acre is shown in the following tabulation:

Old-growth			Mixed-age		
Saw logs	Pulp logs	Residue	Saw logs	Pulp logs	Residue
46	23	24	32	11	5
49%	25%	26%	68%	23%	9%

The equipment used in this study consisted of a Drott feller-buncher, chain saw, to fell the oversized trees, two Cat 518 rubber-tired grapple skidders, a bulldozer (part-time) and a 17- or 22-inch chipper. The material chipped included unmerchantable trees, tops (branches, needles, and stems), chunks broken from the stem, and small cull or pulp logs made when bucking for saw logs.

A second study, using the same equipment, determined the cost of removing different quantities of logs and chips from four study areas. The results of this determination are shown in Table 2. As would be expected, the higher volume and value of the logs reduces the delivered cost at the mill of the combined logs and chips removed from the areas. The production of chips only, increase the cost from $0.81 to $4.79 per ovendry ton above the cost of producing logs and chips. The cost was also affected by the harvesting method used; the clearcutting regime had lower delivered costs than the partial cuts. At an assumed production rate of 100 ovendry tons per day, whole tree chipping cost was calculated to be $22.34 per ovendry ton.

A second phase of the study was concerned with the cost of disposing of logging slash piles by chipping. A crane, chainsaw, and chipper were used in this study part. The average cost of the delivered chips was $70.83 per ovendry ton. This high cost reflects the inefficient use of the machinery. The projected cost of producing an assumed 100 ovendry tons per day of this type of material for fuel was $18.20 per ovendry ton.

Another relevant study was conducted by the Intermountain Forest and Range Experiment Station in western Montana. A three-man crew, Melroe Bobcat, grapple skidder, two chain saws, and a chipper were used to thin and remove insect-infested trees from an 80-year old ponderosa pine stand. Felling and bunching was completed a few days prior to the start of skidding. The grapple skidder pulled the trees to a landing where house and stud logs were cut from the stems. Tops and smaller trees were chipped and the chips hauled to a pulp mill. The chips proved unsuitable for pulp but suitable for fuel. Delivered cost of the chips was not meaningful because this was a family-type operation.

In addition to inwoods chipping, defective logs and trees have been concentrated and trucked to either a pulp mill or to a satellite chipping station in the Northern Rockies. This endeavor also dates back to the pulp chip shortage of 1973 and 1974 and has subsequently been stopped. Much of the timber salvaged for chips was obtained from timber sales where green logs had been harvested and from dead timber located close to roadsides. No special equipment was used to harvest these cull logs. More than 150 million board feet of logs were purchased during a two-year interval. Costs ranged from $50 to $65, per thousand board feet,or $25 to $33 per cord (McMichael 1975).

Pacific Northwest

The Pacific Northwest area is usually divided into western and eastern sections, with the Cascade Mountains as the boundary. The western portion of the region contains many large, overmature stands of Douglas-fir. When these stands are harvested, tremendous tonnages of forest residue consisting of cull logs, dead trees, tops, and unmerchantable trees remain. The average gross weight of bone dry tons per acre has been estimated to be 57 tons (Grantham 1974). The eastern portion contains smaller size timber, with ponderosa pine and lodgepole pine the principal species. The average tonnage of forest residue remaining in these stands after harvesting has been estimated to be about 35 tons per acre.

In the western portion, the steep mountainous terrain and large timber requires the use of cable harvesting systems and heavy logging equipment. Also, chip vans would find it difficult to negotiate the sharp curves in the road system. As a result, timber sales agreements have been developed that require the yarding of much of the forest residue to a landing for later disposal. Yarding of unutilized material (YUM) is the term applied to this method.

The major advantage of the YUM system is that the cost of yarding the low-value, low-quality material is included in developing the sales appraisal. The cost of moving this material to roadside is then borne by the good logs that are harvested.

Another procedure that has been developed and used to a limited extent in this area is termed PAM (per acre material). In timber sales of this type

Table 2. — QUANTITY AND COST OF REMOVING SAW LOGS AND CHIPS FROM FOUR STUDY AREAS IN THE NORTHERN ROCKIES USING DIFFERENT HARVESTING REGIMES

Cutting regime	Quantity harvested				Delivered cost at mill	
	Total		Per acre			
	Logs & chips	Chips only	Logs & chips	Chips only	Logs & chips	Chips only
	(ovendry tons)				(dollars)	
Leave trees 9"	302	241	15.1	12.0	34.35	39.14
Leave trees 6"	529	502	22.0	21.0	32.71	33.67
Clearcut	480	461	22.0	21.0	28.58	29.39
Sanitation cut (insects)	1,198	1,008	29.6	25.0	27.72	31.76

the purchaser pays for the green or sound logs at a fixed price per thousand board feet, log scale, by species. The large cull and small sound logs on the sale area, which contain below a given net volume, such as 80 board feet, would be purchased for a lump sum per acre (Hamilton 1975).

Timber sales of the PAM type tend to encourage the operator to remove all the material that will pay for its handling and hauling costs.

East of the Cascades, timber size, terrain, and forest residue are similar to that encountered in the Northern Rocky Mountain region. Hence, the collection procedures for forest residues that have been developed and used are similar to those described under the preceding section of this report. Feller-bunchers and grapple skidders are commonly used harvesting equipment.

A recent innovation has been use of the Hahn harvester at the landing. With this machine, trees are skidded to the landing intact and fed into the harvester. The machine then delimbs and bucks the tree to the desired length or top diameter. An attachment for the harvester is being developed that will chip the branches and unused top and make this available either for fuel or for pulp.

Transportation of Forest Residues

Historically, two methods have been used for transporting forest residues: (1) where chipping is performed at the harvesting site, chip vans are used, and (2) where chipping is done at the manufacturing plant or reload station, trucks and trailers transport the material in the round.

Two sizes of chip vans are commonly used in the west; a 40-foot van with a capacity of 38,000 pounds and a 45-foot van with a capacity of 42,000 pounds. The 40-foot van is preferred for inwoods chipping because of its greater maneuverability on forest roads. For maximum efficiency, it is necessary that the material to be chipped be concentrated at a landing prior to the chipper being operated. Also, it would be desirable to have two or three chip vans being located at the landing for loading. A single tractor could then be used to pull the loaded vans to the mill or railroad siding and return the empty vans for reloading. The average daily production using this system is about 10 vans, depending on the haul distance.

Because of the many factors involved, such as hauling distance and turnaround time, it is difficult to estimate the exact cost of chip transportation. Withycombe (1975) has estimated this cost to be 5 cents per highway-ton-mile. However, because of the increased care and time required for forest roads, this cost should probably be at least doubled and possibly tripled.

Logging trucks and trailers have been used to transport forest residues in the log form. This equipment has a load capacity of approximately 52,000 pounds or about 5,000 board feet, log scale. The trucks, designed and built for woods hauling, are usually individually loaded at the landing. The forest turnaround time may be fairly long, depending on the size and number of pieces loaded.

The cost of hauling forest residues by this system would be essentially the same as for higher valued green logs destined for lumber or plywood. At this time, the average hauling cost, forest to mill, is about $10 to $15 per thousand board feet, log scale.

Flakeboard Manufacture

Pulp chips are not suitable for the manufacture of structural flakeboard. Heebink (1977) has stated that flakes for structural flakeboard should be fairly long and thin. In his experimental work he was able to produce 2-inch-long and

0.02-inch-thick flakes by first reducing log bolts to pieces termed "fingerling." Fingerlings were approximately 2 to 3 inches long and 3/4 to 1 inch in cross-sectional area. Fingerlings were produced in a modified drum chipper, then the fingerlings were flaked through a ring flaker.

Using the fingerling method, wood residues could be debarked and made into fingerlings in the forest. The fingerlings would be transported to the plant by chip van, processed into flakes, and formed into structural board panels.

An alternative would be to transport the residue in the round to the plant site. Here debarking or cleaning the logs, sawing to optimum length, and processing through the fingerling chipper and flaker could be accomplished. In either event, the cost of producing suitable flakes would exceed the estimated $3 cost of producing pulp chips (Gardner 1978).

A recently published report by Gardner provides detailed information on the use of forest residues using the fingerling approach. The report develops estimated costs per ton for a variety of harvesting systems and includes simulated costs of harvesting residues and producing fingerlings.

Summary

Enormous quantities of forest residues are generated annually on the National Forests of the western United States. The principal areas of concentration of this material are the Pacific Northwest, California, and the Northern Rocky Mountains. At this time, the collection, transportation, and preparation of forest residues for structural flakeboard manufacture appears to be uneconomical. However, equipment and procedures for precessing residues more efficiently are being developed, and the prospects for its increased utilization seem promising.

Within the last few years, research has used two methods to improve the utilization of forest residues. One method has been complete tree harvesting in which the entire tree is brought to a landing and after the more valuable stem wood has been removed the top foliage and branches are chipped. Unmerchantable wood is also chipped at the landing. This method has proved suitable for making pulp chips at times when such chips are in short supply. The method might also lend itself to the production of fingerlings that are then flaked for structural flakeboard.

The second research method has been the removal of selected portions of the forest residue, primarily cull and dead tree logs, to an off-forest site. At this location, the residue logs have been made into pulp chips and could be made into fingerlings. In the Pacific Northwest the traditional sales agreement has been modified to require the yarding of unutilized material (YUM) or a fixed price per acre has been charged for the material (PAM). Forest residues would then be available for use in structural flakeboard.

Although both methods appear promising, the present economic situation is the major constraint. Recent studies indicate that the costs of collecting and transporting forest residue have a range from about $30 to $60 per ovendry ton. These costs far exceed the costs of material from alternative supply sources, sawmills and planing mills. However, new harvesting equipment and systems may reduce the costs associated with forest residue and increase the utilization of this material by all wood using industries, including structural flakeboard.

Technology is presently available for transporting and processing forest residue into structural flakeboard. Chip vans and logging trucks can be used to transport this material and modified drum chippers can produce fingerlings for processing in a ring flaker.

Structural flakeboard is a definite possibility for utilizing the tremendous quantities of forest residues available in the West.

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TWO METHODS OF ACQUIRING RESIDUAL WOOD FOR SOUTHERN FLAKEBOARD PLANTS--THE SHAPING-LATHE HEADRIG AND THE MOBILE CHIPPER

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Abstract

With little disturbance of existing southern wood markets, structural flakeboard plants with annual capacities of 37.5 to 150 million square feet (1/2-inch basis) can be supplied from hardwoods growing on southern pine sites. One sawmill equipped with a 9-foot shaping-lathe headrig (or three 54-inch shaping lathes) and a salvage roundwood flaker can furnish enough flakes to produce 37.5 million square feet of flakeboard annually. Use of three mobile chippers to retrieve logging residues can double wood recovery so that residual flakes and chips are sufficient for a flakeboard plant with annual capacity of 75 million square feet (1/2-inch basis). A sawmill with one 9-foot shaping lathe, three 54-inch shaping lathes, and six mobile chippers could supply flakes and chips for annual production of 150 million square feet (1/2-inch basis). On rough or rocky terrain, skidders and roadside chippers would replace mobile chippers. Clean flakes and chips provided the flakeboard plants by these systems would be priced about the same as pulpwood chips of the same species.

Plants that manufacture structural flakeboard from southern woods offer substantial opportunity for profit; it is likely, therefore, that from 1980 to 1990 several such manufacturing facilities will be constructed. Annual plant capacities will probably range from 37.5 to 150 million square feet (1/2-inch basis). This paper describes two processes by which wood can be obtained for these plants without greatly upsetting existing wood markets in the South.

If made from a mixture of southern species (mostly hardwoods), structural flakeboard weight at shipment will be about 50 pounds per cubic foot or 2,083 pounds per 1,000 square feet (1/2-inch basis). Therefore, plants will require 37,500 to 150,000 tons of dry flakes annually.

Moisture content of stemwood in pine-site hardwoods ranges from a low of 47 percent in green ash to a high of 120 percent in sweetgum. Average moisture content of stemwood from these hardwoods, weighted by the percentages in which they occur, is about 75 percent (dry-weight basis). A ton of dry flakes can therefore be obtained from 1.75 tons of green wood. Accordingly, green wood requirement of the proposed flakeboard plants will range from 66,000 to 263,000 tons annually, depending on plant capacity.

Delivered wood in the form of green flakes, chips, or roundwood should cost the plant \$12 to \$30 per ton on a dry weight basis, \$7 to \$17 per ton on a green weight basis, or \$21 to \$51 per cord on a volume basis. Plants can operate most economically on a 100-percent flake furnish, and least economically on barky roundwood, assuming that flakes, chips, and roundwood are all available at the same price per ton and at the same moisture content.

Because the structure of the hardwood roundwood (i.e., pulpwood) business in the South is well understood, harvesting and delivery techniques for this product will not be further discussed. Instead, this paper concentrates on methods of obtaining residual flakes from other manufacturing operations and on methods to harvest logging residuals with a mobile chipper. Economics of roadside chippers will not be analyzed, because their operation is understood by the industry.

Residual Flakes from the Shaping-Lathe Headrig

In the South, the major underused wood resource is hardwoods on pine sites. In stemwood of trees 5 inches dbh and larger, there is about 0.8 ton of these hardwoods for every ton of pine on southern pine sites. About half of this hardwood volume is in trees 5.0 to 10.9 inches in dbh; the other half of the volume is about evenly divided between trees 11.0 to 14.9 inches in dbh and those 15.0 inches and larger (7).

These hardwoods are of low quality, frequently have short and crooked stems, and contain varying amounts of rot introduced by fire scars, branch stubs, or bird and insect damage. Today, a significant--perhaps major--portion of these hardwoods is unused or destroyed during site preparation for establishment of southern pine.

The shaping-lathe headrig is a new machine designed to convert short logs from such low-quality trees into crossties or posts, cants for resawing, or cylindrical bolts to be rotary peeled. Residue from the headrig is flakes of

uniform length and thickness. These residual flakes (Fig. 1) which can be produced in any thickness from 0.010 to 0.030 inch, are excellent--perhaps the best available--furnish for structural flakeboard manufacture (8).

The headrig is available in three models:

- A pallet-cant machine that converts logs 5 to 12 inches in diameter and 40 to 53 inches in length to cants for resawing into pallet deck boards and stringers (Fig. 2).
- A post, crosstie, and cant machine that converts logs 6 to 9 feet long and 5 to 15 inches in diameter into highway posts, half-ties, full-size ties, or cants for resawing (Fig. 3).
- A roundup machine that converts 8-1/2-foot long bolts up to 30 inches in diameter into the largest perfect cylinders within such logs; these cylinders can be subsequently peeled into continuous veneer (Fig. 4).

To simplify discussion, only the 9-foot headrig (Fig. 3) will be analyzed to assess its ability to provide flakes for the proposed flakeboard plants and a variety of rough green or air-dry products for different markets.

For the industrial market, the headrig can provide: cants to be resawn into pallet or container shook; light timbers to 9 feet in length; industrial blocking of odd cross-section, e.g., round, hexagonal, or octagonal; and hexagonal cants to be crosscut into industrial block flooring.

For the railroad and highway market, the headrig can provide: one piece crossties and dowel-laminated crossties to 9 feet in length (Fig. 5) and highway posts (round or square) in lengths from 4-1/2 to 9 feet.

For the customer market (via retail yards), the headrig can provide: fence post (4-1/2 to 9 feet long), fence rails (6 to 9 feet long), cants for resawing into 8-foot studs or 4 x 4's, cabin logs, and architectural crossties for use in landscaping.

For the furniture market, the headrig can provide: cants in 6- to 9-foot lengths for conversion to furniture dimension stock, rounded-up veneer bolts or cants for slicing, and crosstie side lumber.

To keep the flakeboard plant operating at full capacity, the headrig should run 3 shifts a day, 5 days a week, 48 weeks of the year. Because about 25 percent of wood volume received on the sawmill's merchandising deck will be too crooked, rotten, small, or large for processing through the shaping lathe, this portion will go directly to a disk or drum flaker. Both shaping-lathe headrig and salvage roundwood flaker make some fines; as much as 5 percent of all flakes may be screened out for use as fuel and will not be available to the flakeboard plant.

Since the total flake requirement of the smallest flakeboard plant would amount to 37,500 tons (dry) annually, the sawmill must produce 164 tons (dry) of flakes daily, i.e.,

$$\frac{37,500}{240}/0.95.$$

Of this amount, 75 percent (123 tons) will come from the shaping lathe, and 25 percent (41 tons) will come from the salvage roundwood flaker.

Log shapes and likely machining patterns indicate that the shaping lathe will probably produce equal weights of flakes and cants. Daily input of bark-free logs to the shaping lathe will therefore need to be about 246 tons on a dry weight basis, 430 tons on a green weight basis, or about 13,500 cubic feet per day. This amounts to 4,500 cubic feet of logs per 8-hour shift.

The shaping-lathe headrig is designed to machine 1,440 logs per shift into cants, i.e., four logs per minute for 360 minutes of each shift. If 1,440 logs are to contain 4,500 cubic feet of wood, each log must average 3.13 cubic feet. If logs processed average 92 inches long, they need to average about 8.7 inches in mid-length diameter to contain 3.13 cubic feet. This average diameter is about right for a mill producing half ties (Fig. 3 top, Fig 5), highway posts, and cants for resawing (Fig. 3 bottom).

Accordingly, one 9-foot shaping-lathe headrig and one salvage roundwood flaker will easily supply the wood for a plant producing 37.5 million square feet of 1/2-inch flakeboard annually. The price at which flakes are transferred from lumber mill to flakeboard plant might be about the same as that of pulp chips of the same species mix. (See Koch 1976 and Koch and Caughey 1978 for estimates of the cost of such a sawmill).

Loggers might harvest about 4,500 acres per year of southern forests stocked with low-grade hardwoods to get the logs required, i.e., 1,440 logs per shift averaging 92 inches long and 8.7 inches in diameter at mid-length. This would call for land that contained about 88 trees per acre averaging 20 feet of merchantable stem usable on the headrig.

If the land available had too few

logs of 8.7-inch diameter, but had smaller bolt wood averaging 6.5 inches in diameter, and 40 to 53 inches long, then three 54-inch machines designed to make pallet cants (Fig. 2) should be used in place of the 9-foot shaping lathe.

Mobile Chipper

Since the flakeboards discussed in this paper have 3 layers it is possible to use flakes of low quality in the core and save the best flakes (e.g., those from a shaping-lathe headrig or roundwood flaker) for face material. A low-cost source of core flakes is large pulp chips (maxi-chips) processed through a ring flaker.

While such chips might be purchased, I propose to get them by harvesting cull trees and logging slash with a mobile chipper (Fig. 6). Chips (Fig. 7) would then be split 30:70 between fuel (fines and barky chips) and appropriately sized mostly bark-free chips to be ring-flaked for core material.

Three mobile chippers with associated equipment (Fig. 6) should recover 90,000 tons (green basis) of chips annually, 70 percent of which would be suitable for core material (63,000 tons on a green basis or 36,000 tons on a dry basis). Hardwood residue harvested in this fashion should cost about $14 per green ton delivered to the flakeboard plant, or $24.50 per dry ton (Koch and Nicholson 1978). Each machine should annually traverse about 1,500 acres containing heavy logging slash and many standing culls.

The 27,000 tons (green) annually of fuel is enough to fire four burners continuously, each producing 5.5 million BTU hourly (Fig. 8; see also Koch et al. 1978).

Accordingly, a flakeboard plant producing 75 million square feet of 1/2-inch flakeboard annually and requiring 75,000 tons (dry basis) of wood could be supplied by residues from a sawmill equipped with one 9-foot shaping-lathe headrig (or three 54-inch headrigs) and from logging slash recovered from 4,500 acres per year by three mobile chippers. Plants of larger annual capacity, e.g., 150 million square feet (1/2-inch basis), could obtain their wood from a mill utilizing one 9-foot shaping-lathe headrig, three 54-inch shaping lathes, and six mobile chippers that recover logging residues and cull trees from about 9,000 acres per year.

Mobile chippers (Fig. 8) will be operable on, for example, south Georgia terrain or along the Texas-Louisiana border, but they will not be practical on steep rocky slopes such as those in West Virginia or northern Arkansas. In these areas, it would be more economical to skid residues to roadside chippers.

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Fig. 1. - Face flakes 0.015 inch thick and three inches long in random widths produced on the shaping lathe. Top left, white oak (Quercus alba L.); top right, southern red oak (Quercus falcata Michx.); center left, hickory (Carya spp.); center right, sweetgum (Liquidambar styraciflua L.); bottom left, southern pine; and bottom right, the five species mixed.

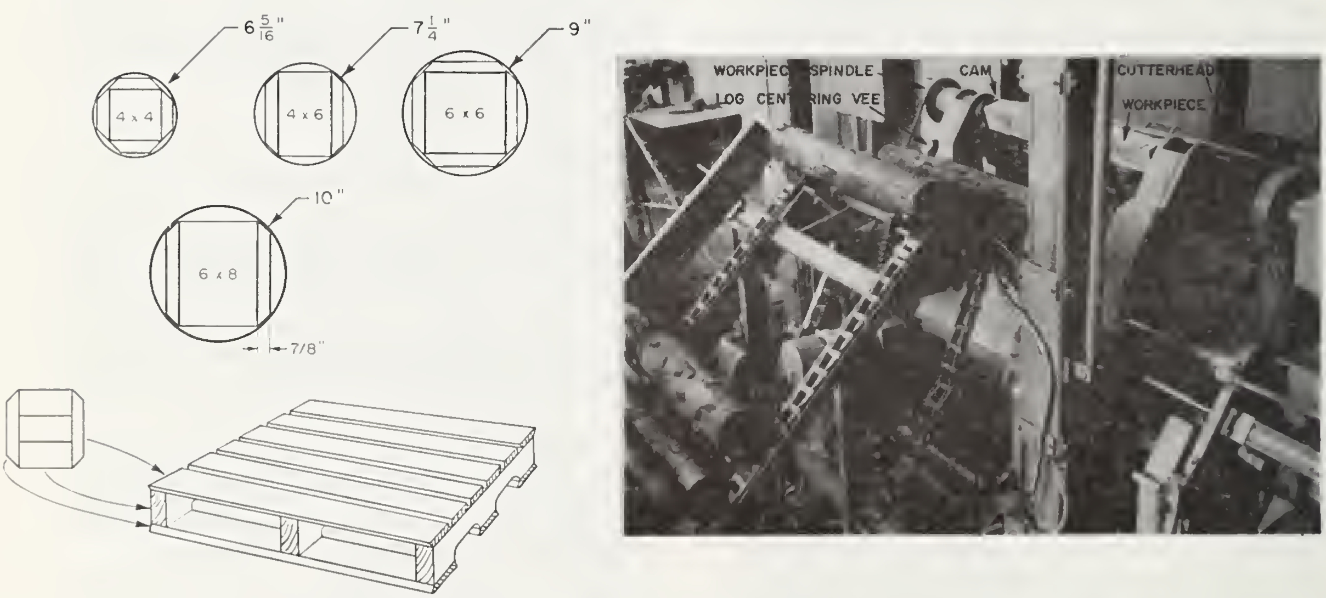
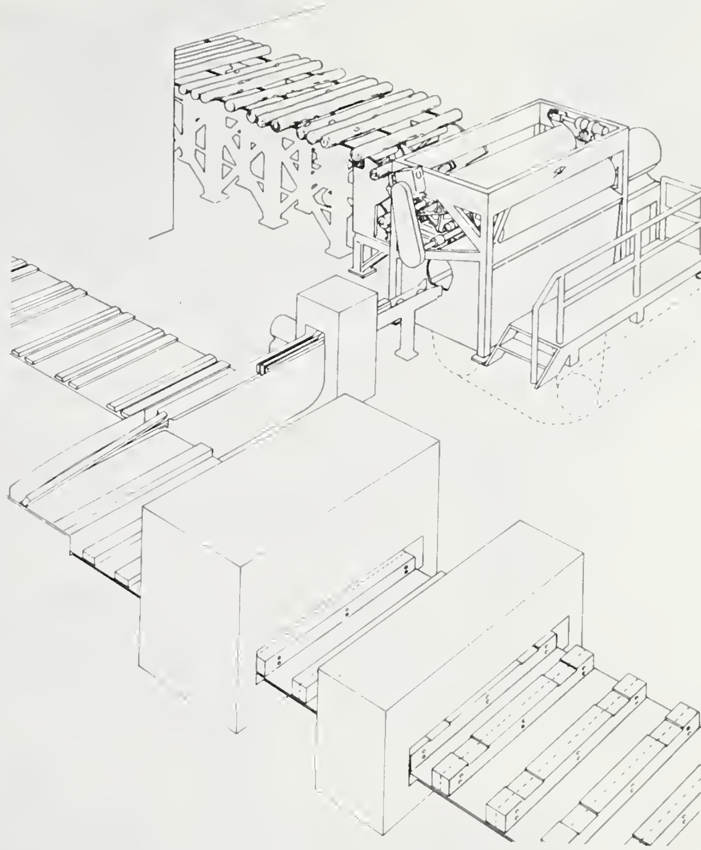


Fig. 2 - (Top) Shaping-lathe headrig for manufacture of pallet cants can handle logs 40 to 53 inches long and 4 to 12 inches in diamater. Key elements (arrows) are: lower left, log deck and unscrambler; upper left, log centering vee and workpiece spindle; center top, cam; upper right, workpiece, cutterhead and charger; lower center, take-away belt. (Bottom) Cants from headrig can be sawn into deckboards and stringers for pallets (Koch 1975).



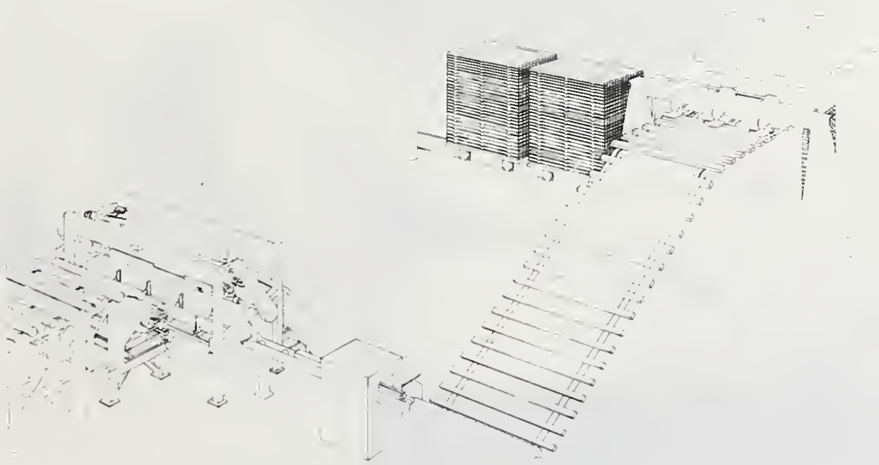


Fig. 3 - Shaping-lathe headrig for logs 6 to 9 feet long and 5 to 15 inches in diameter. The headrig yields cylindrical, octagonal, and hexagonal shapes as well as rectangular or square. (Top) Mill layout for production of doweled crossties and side lumber. (Bottom) Mill layout for cants to be resawn into lumber, e.g., studs.

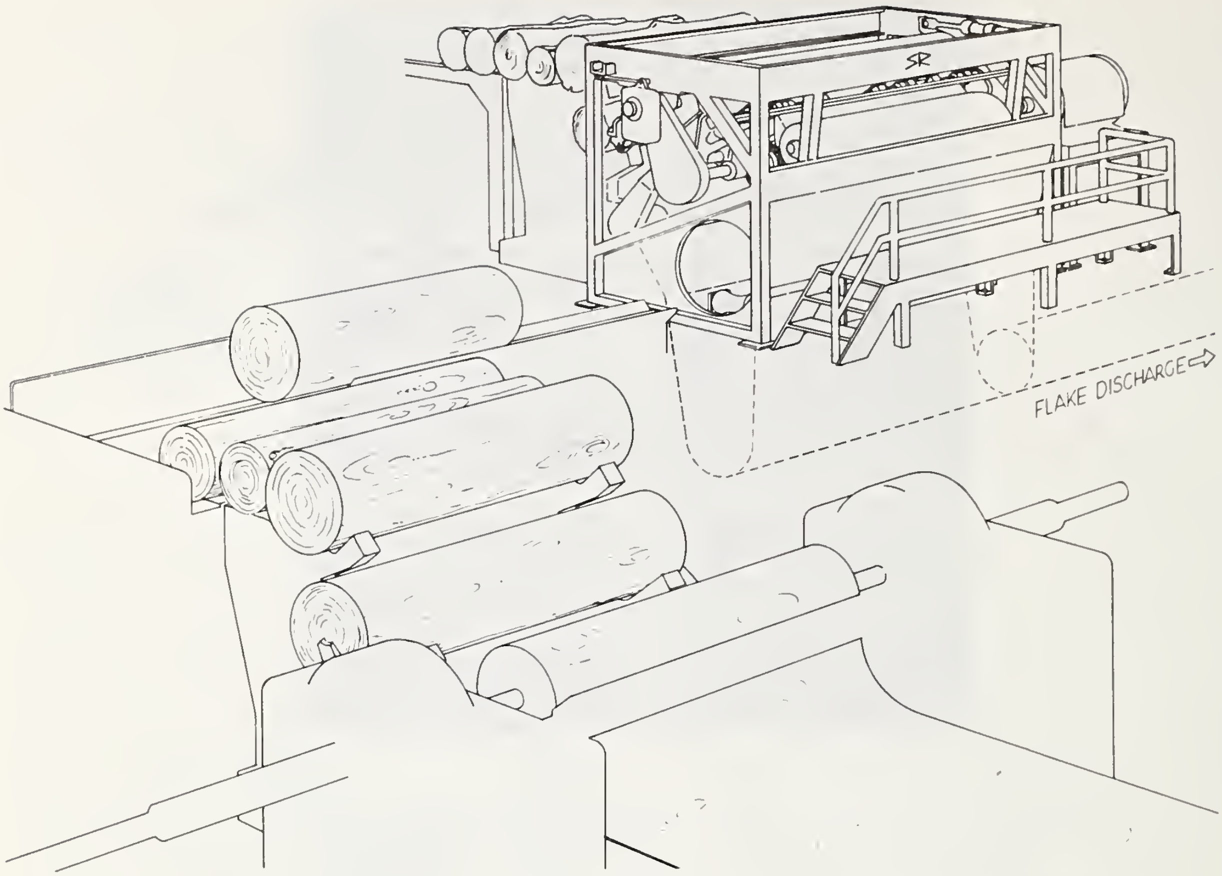


Fig. 4 - Roundup-shaping-lathe to produce flakes and cylindrical peeler bolts yielding continuous veneer from logs 8-1/2 feet long and up to 30 inches in diameter. For a description of this operation see Springate et al. (1978) and Springate (1978).

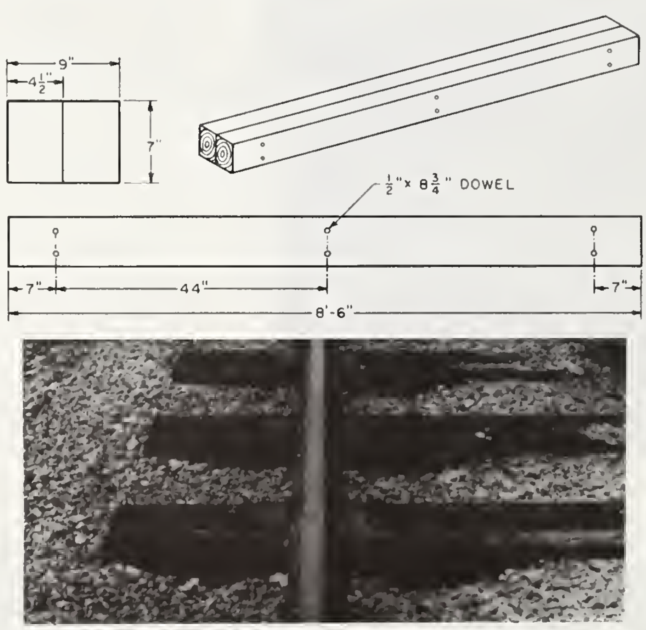


Fig. 5 - (Top) Dowel-laminated crosstie secured with three pairs of 1/2-inch spirally fluted steel dowels. No adhesive used. (Bottom) These steel-doweled mainline ties have been made from logs 8.5 inches in diameter, a size in plentiful supply (Howe and Koch 1974).

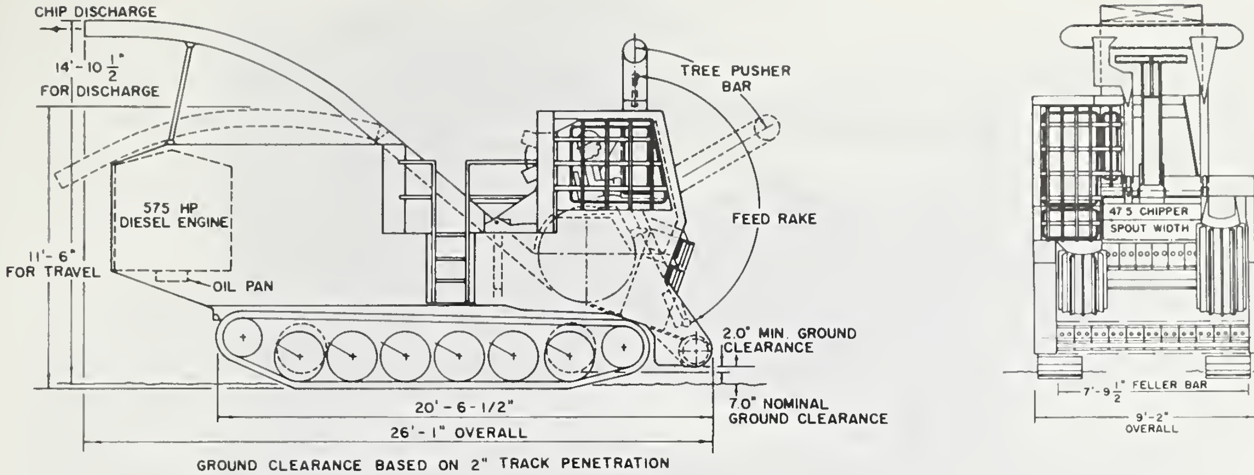


Fig. 6 - Mobile chipper for retrieval of cull trees and logging residues. (Top) Prototype machine. (Bottom) Three machine team capable of traversing an acre an hour and delivering chips into roadside inventory piles (Koch and Nicholson 1978).

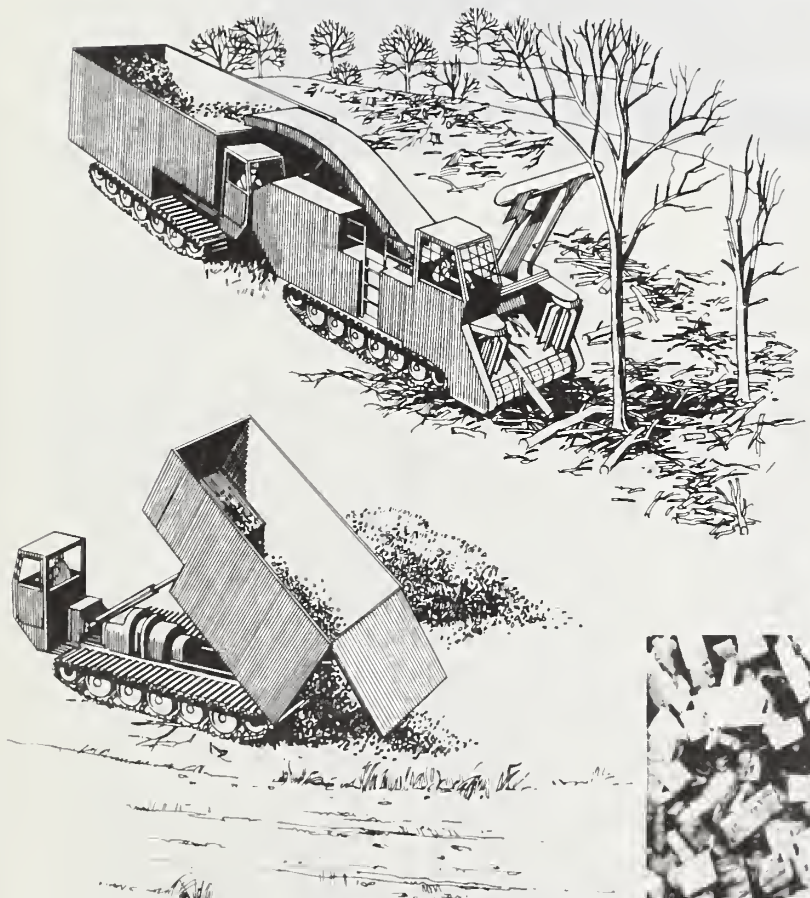
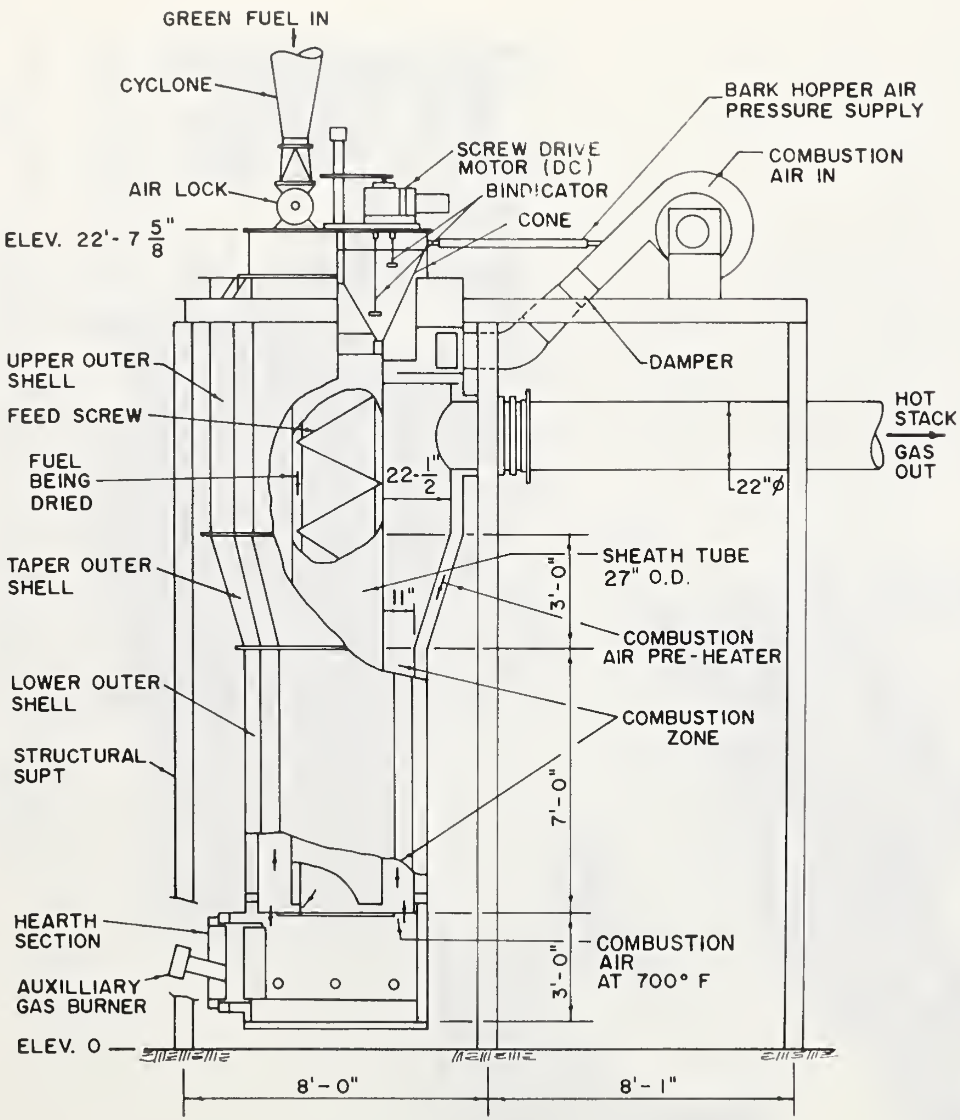


Fig. 7 - Chips from prototype mobile chipper measure about 1 inch long. Feed design could be modified to attain longer lengths if required.



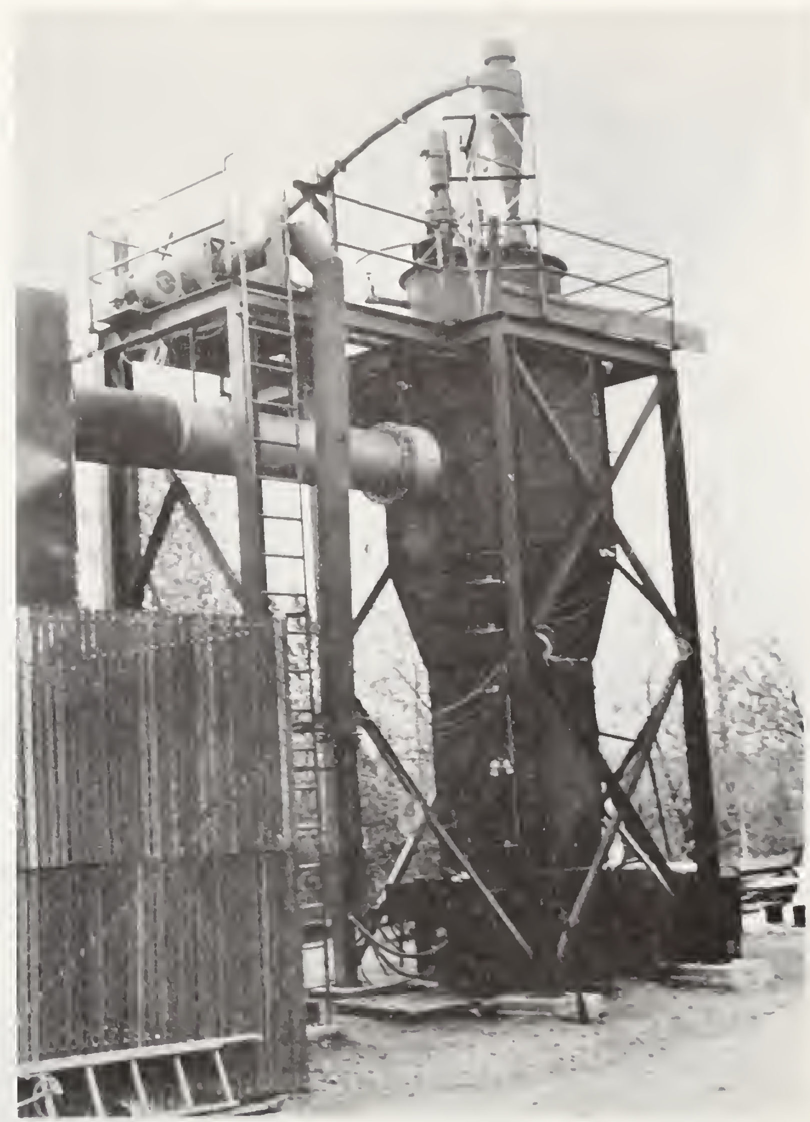


Fig. 8 - Suspension burner for hogged green wood or bark. Exiting hot exhaust gas can directly heat kiln, or can heat a boiler to produce steam for process use and power generation. (Left) Diagram of flow of fuel, combustion air and exhaust gas. (Right) Complete burner at Portland, Oregon, test facility (Koch et al. 1978).

FLAKING ALTERNATIVES

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Abstract

Three-layer structural flakeboards were prepared at two densities and two resin contents (5 and 8%) from flakes cut on a shaping-lathe headrig and on disk, drum, and ring flakers. Panels were made from lodgepole pine (Pinus contorta Dougl.), loblolly pine (Pinus taeda L.), sweetgum (Liquidambar styraciflua L.), southern red oak (Quercus falcata Michx.), and mockernut hickory (Carya tomentosa Nutt.).

The ring flaker produced 23.7% fines; the drum, lathe, and disk produced only 7.7, 3.5, and 2.2% fines. Of the flakes used for panel fabrication, i.e., those retained on a 1/16-inch and larger screens, lathe- and disk-cut flakes had the lowest specific surface and therefore most resin applied per thousand square feet of flake surface area.

Flakes averaged about 2.25 inches long (except ring-cut oak and hickory flakes, which were slightly shorter). Flakes were slightly less than 0.02-inch thick (except for disk-cut flakes which were slightly thicker).

When panels of the low-density species (lodgepole and loblolly pines and sweetgum) were analyzed, bending strength, modulus of elasticity, internal bond, linear expansion, and thickness swell were all strongly influenced by interactions of main factors (flaker, species, resin content, and compression ratio). Such interactions would not allow simple comparisons of the main factors. Flaker types were therefore compared over a range of compression ratios for each individual species of wood. Lodgepole pine boards had highest bending strength and modulus of elasticity when made from lathe-cut flakes, and highest internal bond strength when made from ring-cut flakes. The flake-type yielding least linear expansion and thickness swell varied with conditioning cycle (24-hour water soak, 30 to 90% RH, or ovendry vacuum-pressure soak).

Loblolly pine boards made at low compression ratios were strongest and stiffest if made from disk-cut flakes; at high compression ratios lathe-cut flakes made boards of highest bending strength and modulus of elasticity. Internal bond strength of loblolly pine boards was highest when made from ring-cut flakes, but boards made from lathe-cut flakes had most stability.

At high compression ratios, sweetgum panels had highest bending strength and modulus of elasticity when made from disk-cut flakes but highest internal bond strength when made from ring-cut flakes. Sweetgum boards were most stable when fabricated from lathe-cut flakes.

At any compression ratio from 1.20 to 1.50, lodgepole pine boards generally had lowest modulus of rupture, modulus of elasticity, and internal bond strength. Loblolly pine and sweetgum boards often had similar properties.

When oak and hickory boards were evaluated, those made from lathe-cut flakes had highest bending strength and stiffness. Increasing resin content from 5 to 8% improved bending properties; the degree of improvement was affected by species and flaker type. Internal bond strength was highest in boards made of ring-cut flakes and was greatly influenced by resin content and species. Linear-expansion values were low in panels of drum-cut flakes pressed to high compression ratios and for boards of lathe-cut flakes at low compression ratios. Thickness swell of oak and hickory boards was inversely correlated with resin content. Most properties of red oak flakeboards of 52.6 pcf density were superior to hickory boards of this density but were inferior at equivalent compression ratios.

Overall, use of disk and lathe flakers yielded boards with higher bending strength and modulus of elasticity for initial test condition (50% RH) and after accelerated aging. Internal bond strength of boards made of ring-cut flakes (132 psi) was the highest. Despite their higher internal bond strengths, boards made of ring-cut and drum-cut flakes were less stable after being subjected to environmental conditioning than boards made from lathe- and disk-cut flakes. In general, species with higher wood densities had higher measured property values. Also, the higher density species generally had a larger percent loss in properties after aging.

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Introduction

Logging residue from many regions is being evaluated by the Forest Service to provide technical data on the feasibility of using such residue in structural sheathing. Western residues are mostly from softwoods; small, cull, low-grade hardwoods comprise the residue from the South. Development of a structural panel utilizing the western residue has been the concern of the Forest Products Laboratory (FPL). The Southern Forest Experiment Station (SO) has concentrated on the southern residue. Each laboratory has recommended three-layer panels, but differences in flakes and particles have dictated different layering and particle geometries.

At least four types of commercial machines exist for producing the large quantities of flakes required for structural flakeboards: the disk, drum, and ring flakers and the shaping-lathe headrig. The objective of this study was to determine the characteristics of structural flakeboards made from flakes produced by each of these machines.

Results of a screen analysis are given in Part I. Part II analyzes the properties of panels made from sweetgum, lodgepole pine, and loblolly pine (low-density species) and fabricated at compression ratios (ratio of panel density to species density) of 1.25 and 1.50. Part III reports the properties of red oak and hickory panels fabricated at a compression ratio (CR) of 1.25, and at a second CR such that the density of the panels was 52.6 pounds per cubic foot (pcf). In Part IV, major factors--resin content, species, and flakers--are discussed in attempting to decide which flaker is best overall.

Procedure

Small-diameter bolts (about 7 inches) of sweetgum (Liquidambar styraciflua L.), red oak (Quercus falcata Michx.), mockernut hickory (Carya tomentosa Nutt.), and loblolly pine (Pinus taeda L.) were obtained in central Louisiana. Small-diameter lodgepole pine (Pinus contorta Dougl.) logs were obtained in Colorado and shipped to Louisiana. Material of each species was randomly divided for flaking with a disk flaker located at FPL, ring flaker at FPL, shaping-lathe at SO, or drum flaker at Washington State University. Before flaking, all material was debarked by hand. The flakers were calibrated to produce flakes 2.25 inches long, 0.020 inch thick, and random width. Bolts to be flaked with the ring flaker were first chipped in a drum chipper that produced chips 2.50 inches long and then flaked. The shaping-lathe employed circular cams decreasing at the rate of 1 inch per revolution down to a 4-inch diameter. The drum flaker feeding mechanism pivoted through a small angle.

Lathe flakes were dried to less than 10% moisture content and shipped to FPL. Drum flakes were shipped green to FPL with a small amount of formaldehyde added to inhibit mildew and fungus contamination. Before panel fabrication, all flakes were dried to about 3% moisture content and screened through 2, 1, 1/2, 1/4, 1/8, and 1/16-inch screens. The material that passed through the 1/16-inch screen was discarded after the percentage of the total weight that it composed was calculated. Accepted flakes were divided into equal weight fractions of large and small flakes; three-layer boards were constructed with the small flakes in the core and large flakes equally divided between face layers.

For each species and flaker combination, two-panel replications were fabricated for each of two resin contents (5% and 8% based on ovendry weight of flakes) and two densities. For all species a panel density was established at a CR of 1.25. Additional flakeboards of sweetgum and both pines were made at a CR of 1.50. Additional oak and hickory boards were pressed to 52.6 pcf.

Board Manufacture

Panel manufacturing conditions were:

- Panel size: 1/2 inch by 24 inches by 28 inches
- Binder: Phenol-formaldehyde liquid resin
- Additive: 1% wax emulsion (based on OD weight of flakes)
- Mat moisture content: 9-10%
- Mat construction: three-layer, with the small flakes in the core and large flakes equally divided between face layers
- Press temperature: 340°F
- Press cycle: 1 minute to thickness, then pressure necessary to maintain position
- Total press time: 8 minutes
- Postcure: Immediately after pressing, panels were hotstacked overnight in an insulated box.

Testing the Panels

After manufacture, the unsanded panels were cut into test specimens, conditioned at 50% relative humidity (RH), and tested according to ASTM D 1037-72a (1972). Four specimens were tested for bending at 50% RH and two after accelerated aging (AA). Bending strength (MOR) and stiffness (MOE) or aged specimens were calculated based on specimen dimensions before aging.

Two internal bond (IB) specimens were cut from each tested bending specimen. Dimensional stability tests were

performed on specimens subjected to ovendry vacuum-pressure soak (OD-VPS) (Heebink 1967), relative humidity exposure between 30 and 90% at 80°F, and 24-hour water soak (WS).

Results and Discussion

Part I -- Screen Analysis and Resin Coverage

The percentage of fines varied significantly by flaker (figs. 1-5).[2] The ring flaker produced from 21.4 to 25.6% fines depending on the species (table 1). Drum, lathe, and disk flakers yielded 7.7, 3.5, and 2.2% fines. The most fines the lathe and drum flakers produced was in cutting oak (6.9 and 12.4%). The disk flaker made most fines when cutting lodgepole pine and hickory (3.2 and 3.5%).

From the material that was to be used in panel fabrication, 50 flakes per screen size were measured for length, width, and thickness.[3] Disk-cut flakes had the smallest surface area per pound of flakes followed by the lathe-cut flakes (table 2). Ring-cut flakes had the largest surface area per pound except for loblolly pine for which drum flakes had the largest. Since constant amounts of resin were applied (5 or 8%), resin solids applied per thousand square feet of flake surface area were inversely correlated with surface area per pound of flakes.

A flake length to thickness ratio of 112.5 was anticipated, i.e., 2.25-inch target flake length/0.020-inch target flake thickness. Although very few flakes remained on the 2-inch screen (table 1), average length exceeded 2 inches for flakes remaining on screens as small as 1/2 inch. In general, flake thickness did not change with screen sizes above 1/2 inch, and the thinnest flakes were on the 1/16-inch screen. Except with the disk flaker, the anticipated length to thickness ratio of flakes retained on 1/2-inch and larger screens was achieved (fig. 6). The low disk-flaker ratio occurred because flake thickness exceeded target thickness; the other flakers yielded slightly less than target thickness. Dimension ratio varied more for core flakes than face flakes.

Part II. Flaking alternatives for low-density species

Bending Strength (MOR)

The interactions of resin content with flaker type, species with flaker type, and species with CR were significantly related to MOR for sweetgum, loblolly pine, and lodgepole pine. When the data were analyzed by flaker and CR, the only combination having a significant interaction was drum-flake panels with low CR.

Increasing resin content from 5 to 8% raised MOR an average of 15% at the lower compression ratio and 10% at the higher compression ratio. The MOR of the ring-flake panels increased 20% with resin content; the MOR of disk-flake panels increased least (3%). The MOR increased 12 and 14% in lathe- and drum-flake panels.

Expressing panel densities as CR, averaging the resin contents, and assuming a linear relationship with MOR over the CR data range allowed analysis of the species with flaker interaction--without the confounding effect of fabrication CR variability (table 3, figs. 7 and 8). Lodgepole pine panels made from lathe flakes had higher initial-condition (50% RH) bending strength than lodgepole pine panels made of the other flakes. Although the ring- and disk-flake lodgepole pine panels had lower initial MOR values, both had higher AA values than the lathe-flake panels at high CR. In both initial and AA tests, the drum-flake panels had lower MOR than the lathe-flake panels.

With one exception (loblolly pine panels at low CR after AA), loblolly pine and sweetgum panels of drum-cut flakes had the lowest MOR for the initial condition and after AA. Under initial conditions, loblolly panels of disk flakes at low CR and of lathe flakes at high CR had high MOR's. The values for ring panels were intermediate at low and high CR. After AA, the disk panels maintained the high MOR for loblolly panels at low CR, but the ring panels had the highest MOR at high CR. For sweetgum, the disk was high at the high CR and ring panels at low CR.

The ring-flake panels under initial conditions had MOR's proportional to the densities of the species (table 3). Panels made of lathe-cut and drum-cut flakes showed little variation among species in initial MOR. Panels of drum-cut flakes had the lowest MOR for all species and the slope of the MOR/CR relationship increased with species density.

Modulus of Elasticity (MOE)

An increase in resin content did not increase average MOE as much as it did average MOR; the increase in MOE was 7.4% and the increase in MOR was 12%. Increasing resin content from 5 to 8% increased MOE of ring-flake panels 13.5%. Drum-flake panels had an 8.7% increase;

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[2] Statistical data for the study are available from the authors.

[3] Tables containing these data are available from the authors.

Table 1.--Percent of material retained on each screen size

Species and Flaker	2	1	1/2	1/4	1/8	1/16	Fines[1/]
	Percent						
Lodgepole pine							
Disk	4.1	48.7	25.9	11.6	3.2	3.3	3.2
Drum	1.7	45.2	20.8	13.1	6.3	5.7	7.2
Ring	0.	.4	5.6	31.8	20.6	20.1	21.4
Lathe	.3	56.8	27.3	10.2	1.5	1.4	2.8
Loblolly pine							
Oisk	5.8	61.2	23.8	5.7	1.1	1.1	1.3
Orum	0	24.6	33.5	19.6	8.3	6.9	7.1
Ring	0	.2	2.4	25.4	24.0	22.4	25.6
Lathe	0	17.8	44.5	25.9	4.5	3.2	4.1
Sweetgum							
Disk	4.3	60.3	23.8	7.6	1.4	1.1	1.5
Drum	0	39.4	31.4	13.8	5.9	4.8	4.7
Orum, +1A[2/]	0	1.8	32.2	34.9	14.1	9.3	7.7
Ring	0	.1	3.8	31.9	19.4	20.1	24.7
Lathe	0	64.3	27.2	5.5	1.0	.7	1.3
Red oak							
Oisk	1.2	39.0	35.5	19.0	2.4	1.2	1.7
Drum	0	4.5	19.5	36.7	14.7	12.2	12.4
Ring	0	0	.5	22.0	25.8	26.2	25.5
Lathe	0	4.6	28.0	44.1	9.9	6.5	6.9
Hickory							
Disk	.9	46.9	27.2	13.5	4.8	3.3	3.5
Disk, + 1A[2/]	0	4.2	42.1	33.1	11.0	4.8	4.8
Drum	0	25.9	32.3	20.7	7.9	6.3	6.9
Drum, +1/2A[3/]	0	.7	10.3	49.6	17.7	11.9	9.8
Ring	0	0	1.7	25.7	27.8	23.7	21.1
Lathe	1.0	33.8	34.1	21.1	5.3	2.4	2.3

1/ Material that passed through the 1/16-inch screen.
2/ Flakes on the 1 and larger screens were passed through the drum chipper, added to the other screens, and rescreened to yield the tabulated percentages for panel fabrication.
3/ Flakes on the 1/2 and larger screens were passed through the drum chipper, added to the other screens, and rescreened to yield the tabulated percentages for panel fabrication

Table 2.--Flake surface area and resin solids per unit flake area

	SQUARE FEET OF SURFACE AREA								RESIN SOLIOS PER 1000 SQ. FT. OF FLAKE SURFACE AREA			
	Per pound of flakes						Per panel[1/]		5% Resin		8% Resin	
Species and Flaker	2	1	1/2	+1/4"	1/8	1/16	Face	Core	Face	Core	Face	Core
									Pounds			
SWEET GUM												
Disk	30.08	35.27	41.05	45.61	62.80	74.32	132.97	156.07	1.418	1.208	2.269	1.933
Drum	-	52.32	53.91	58.32	80.15	91.30	207.32	269.50	0.909	0.699	1.455	1.119
Lathe	-	47.25	51.30	55.05	58.78	86.42	178.13	192.90	1.058	0.977	1.693	1.563
Ring	-	48.69	58.39	72.99	80.11	86.21	272.66	313.71	0.691	0.601	1.106	0.961
LOBLOLLY PINE												
Oisk	35.49	34.58	34.90	40.41	50.32	58.11	125.53	132.61	1.446	1.369	2.314	2.190
Drum	-	81.35	82.68	83.20	93.62	103.78	297.57	319.48	0.610	0.568	0.976	0.909
Lathe	-	49.67	51.96	55.46	60.76	82.45	185.71	206.85	0.977	0.877	1.564	1.404
Ring	-	62.74	70.29	71.30	80.85	90.93	266.88	315.44	0.680	0.575	1.088	0.921
LODGEPOLE PINE												
Oisk	45.46	51.51	50.49	75.64	96.33	102.83	147.83	184.73	0.971	0.777	1.553	1.243
Orum	68.67	73.80	75.25	94.26	106.79	120.35	211.81	259.98	0.678	0.552	1.084	0.883
Lathe	53.51	73.46	83.69	88.19	98.29	127.69	210.83	243.97	0.681	0.588	1.089	0.941
Ring	-	82.56	87.34	100.41	107.65	128.72	282.10	338.78	0.509	0.424	0.814	0.678
REO OAK												
Oisk	19.92	29.34	31.38	32.36	42.51	59.85	138.43	153.70	1.683	1.516	2.693	2.426
Orum	-	46.14	46.11	52.55	73.62	78.04	228.26	310.46	1.021	0.751	1.633	1.201
Lathe	-	37.86	46.88	57.61	63.39	83.86	229.26	291.17	1.016	0.800	1.626	1.280
Ring	-	-	51.58	75.04	79.10	84.48	355.94	386.15	0.655	0.603	1.047	0.965
HICKORY												
Oisk	-	22.30	22.01	25.94	31.87	52.21	122.92	166.62	2.269	1.674	3.630	2.678
Orum	-	35.60	35.44	41.98	43.61	74.28	221.85	287.15	1.257	0.971	2.011	1.554
Lathe	26.20	30.50	33.39	34.98	38.75	75.70	174.96	205.24	1.594	1.359	2.550	2.174
Ring	-	-	63.80	65.59	65.70	73.97	365.61	394.13	0.763	0.708	1.221	1.132

1/ The panels were 1/2 inch by 24 inches by 28 inches for 1.25 compression ratio.

disk-flake panels, a 5.3% increase; and lathe-flake panels, a 2.7% increase. The increase in MOE of ring- and drum-flake panels caused by adding resin were significant for all test condition-CR combinations, but the MOE of disk-panels significantly increased only at low CR under initial conditions. Increasing resin content did not affect the MOE of lathe-flake panels.

As with MOR, assuming a linear relationship between MOE and CR, and averaging the two resin contents allowed analyses of flaker-species interactions without the confounding effect of fabrication CR variability (table 3, figs. 9 and 10). At initial condition, the lathe produced the stiffest lodgepole and loblolly pine panels at the high CR. After AA, the only species for which lathe-flake panels were stiffest was lodgepole pine at the low CR. Disk- and ring-flake panels had highest MOE for all other species, test conditions, and CR's. The drum-flake panels generally had the lowest or next to the lowest MOE for all species and test conditions. Lathe-flake panels showed least variation in MOE among species and the ring-flake panels were particularly correlated with species density.

Internal Bond (IB)

Interactions of resin content with species and flaker, and interactions of flaker and compression ratio were significant for initial and AA tests. One explanation for the complicated interactions may be differences in resin coverage among panel types. For example, at initial condition boards made from drum flakes had a substantial species-CR interaction in which the IB's of sweetgum panels were correlated with CR, but the IB's of loblolly and lodgepole pine panels were not (fig. 11). Large sweetgum flakes were passed through a drum chipper to reduce their width (see footnote 2 of table 1), but large flakes of lodgepole and loblolly pines were not. Putting the sweetgum flakes through the drum chipper may have allowed them to receive more uniform resin distribution. Surface area per pound of material and material bulk density also may have affected resin distribution.

Whether one relates flakers to individual species or to the average of all three species, ring-flake panels had highest IB followed by disk-, lathe-, and drum-flake panels (figs. 11 and 12). The 3% resin content increase generally increased IB of panels under initial and AA conditions; the average increase was 31% for initial IB (68 to 89 psi) and 111% after AA. The significant interaction of resin content with species meant that the higher density species, loblolly pine and sweetgum, had smaller increases in initial IB with increased resin, i.e., lodgepole pine had a 44% increase, loblolly pine 34%, and sweetgum 17%.

Lodgepole pine panels made with ring, disk, or lathe flakes had lowest IB of the three species (table 3). Lodgepole and loblolly pine panels of drum flakes had about the same IB's. Loblolly pine panels of ring or lathe flakes generally had a higher IB than sweetgum for equivalent CR's. Sweetgum panels had highest IB's among panels made of disk-cut flakes. After AA, the IB's were drastically reduced. However, the species-flaker relationships generally remained the same as the initial relationship.

Linear Expansion (LE)

Linear expansion data were stratified by each major variable for the three environmental treatments (table 4). For all experimental conditions, the OD-VPS treatment caused most LE and the WS least LE. With few exceptions, if a change in LE occurred as the CR increased, LE increased for 30 to 90% RH and decreased for WS and OD-VPS (fig. 13).

Panels made of lathe flakes had less LE than any of the other panels for all species under the OD-VPS cycle. For 30 to 90% RH, drum flake panels had the least LE for lodgepole pine, lathe-flake panels for loblolly pine, and ring- and lathe-flake panels were about the same for sweetgum (table 4). In the WS cycle, lathe-flake and disk-flake panels had the least LE at low CR for lodgepole and loblolly pines and lathe-flake panels had least LE at both CR's for sweetgum. Lodgepole and loblolly pine panels of disk flakes had lowest LE at high CR in the WS cycle.

Lodgepole pine generally had the least LE for the OD-VPS condition for all flakers (fig. 13). In general, LE did not increase greatly with increasing CR; exceptions were lathe-flake panels of loblolly given the OD-VPS cycle and loblolly ring- and disk-flake panels given 30 to 90% RH cycle.

Thickness Swell (TS)

In general, 30 to 90% RH caused the least TS, WS caused slightly more, and the OD-VPS caused about twice as much TS as the 30 to 90% RH cycle. Increasing resin content had least effect under test conditions that caused the least TS; adding to the resin content decreased TS by 2.7, 4.0, and 7.6% for 30 to 90% RH, WS, and OD-VPS cycles.

The drum-flake panels had no combination of species and test cycle that produced a low TS (table 4). Disk-flake panels made with sweetgum flakes had a TS for the 30 to 90% RH cycle close to the lathe's. Especially at the high CR, loblolly and lodgepole pine disk-flake panels had little TS for the WS. Ring-flake

Table 3.--Strength properties of panels made from flakes of three species. Flakes were cut on four types of flakers and panels pressed to 1.25 and 1.50 compression ratios

Flaker	Species[1]	Panel density at 50% RH	Bending strength Initial[2]	Bending strength AA[2]	Modulus of elasticity Initial	Modulus of elasticity AA	Internal bond Initial	Internal bond AA
		---pcf---	-------psi-----		----1000 psi----		------psi----	
Ring	LP	28.9	3,141	2,837	432.8	390.7	68.6	35.3
		34.3	4,878	4,542	589.8	591.8	101.7	60.1
	LL	37.4	4,200	3,569	555.0	483.8	96.6	44.8
		42.6	5,397	4,879	691.1	638.9	133.7	69.0
	SG	37.6	3,936	3,151	543.1	449.9	82.7	15.4
		45.5	5,714	4,913	753.0	680.7	137.3	18.9
Disk	LP	30.5	3,358	3,013	514.4	462.0	70.6	33.3
		35.9	4,892	4,987	660.6	683.2	97.5	46.8
	LL	38.1	4,609	3,825	603.2	527.7	82.3	33.3
		45.1	5,806	5,112	746.9	671.0	103.9	55.9
	SG	40.9	4,803	4,133	649.2	568.2	92.2	33.7
		45.7	6,773	5,980	842.8	810.8	113.2	40.4
Lathe	LP	32.6	4,738	4,189	615.2	555.0	47.8	10.9
		38.4	6,490	4,941	802.2	726.4	56.7	7.9
	LL	38.1	4,026	2,973	568.5	417.7	59.7	24.9
		42.5	5,415	4,452	725.1	617.4	87.8	30.4
	SG	40.4	4,231	3,419	575.6	416.1	60.0	17.6
		47.7	6,356	5,328	758.6	622.7	77.0	17.9
Orum	LP	31.6	3,631	2,967	537.2	425.0	43.2	11.9
		39.1	4,621	3,284	699.8	503.4	44.8	8.9
	LL	40.0	4,068	3,532	591.1	478.2	42.3	21.3
		46.7	5,574	4,978	793.8	676.4	47.3	16.1
	SG	40.0	3,573	3,048	498.1	385.9	52.3	21.4
		47.5	5,601	4,726	709.9	588.7	91.3	26.8

[1]LP = lodgepole pine, LL = loblolly pine, SG = sweetgum.
[2]Initial = 50 RH, AA = After accelerated aging.

Table 4.--Dimension stability properties of panels made from flakes of three species cut on four types of flakers and pressed to 1.25 and 1.50 compression ratios

Flaker	Species[1]	CR[2]	Linear expansion 30-90% RH	Linear expansion 24-HR WS[3]	Linear expansion OD-VPS[3]	Thickness swell 30-90% RH	Thickness swell 24-HR WS	Thickness swell OD-VPS
			----------------------------Percent----					
Ring	LP	1.22	.15	.11	.26	14.2	18.5	23.6
		1.45	.16	.08	.23	15.4	15.9	22.3
	LL	1.26	.12	.11	.27	14.4	18.9	25.9
		1.43	.14	.09	.26	14.7	19.3	30.1
	SG	1.21	.15	.10	.28	16.1	22.4	31.2
		1.47	.14	.03	.24	16.8	19.9	35.5
Disk	LP	1.29	.15	.07	.23	15.1	18.6	24.4
		1.51	.15	.00	.23	14.4	13.2	30.7
	LL	1.28	.13	.07	.23	13.4	17.6	22.2
		1.51	.15	.03	.23	13.9	15.7	31.5
	SG	1.32	.20	.06	.27	13.2	13.9	27.4
		1.47	.20	-.01	.22	13.7	12.5	34.1
Lathe	LP	1.38	.11	.07	.18	11.9	17.9	20.6
		1.62	.12	.06	.17	12.7	22.9	29.3
	LL	1.28	.11	.07	.17	12.2	20.8	23.3
		1.43	.12	.07	.21	13.9	21.2	28.6
	SG	1.30	.15	.01	.21	13.6	9.9	25.5
		1.54	.14	-.07	.15	14.6	9.8	30.9
Orum	LP	1.33	.07	.08	.19	15.8	22.5	28.1
		1.65	.09	.05	.18	15.2	23.8	36.5
	LL	1.34	.14	.11	.23	15.6	26.7	27.6
		1.57	.16	.13	.25	17.3	30.0	33.1
	SG	1.30	.18	.14	.33	14.9	17.1	29.1
		1.52	.20	.06	.31	15.3	12.0	32.7

[1]LP = lodgepole pine, LL = loblolly pine, SG = sweetgum.
[2]CR = compression ratio.
[3]24-HR WS = 24-hour water soak.
OD-VPS = ovendry vacuum-pressure soak.

panels had least TS for the OD-VPS cycle when made of lodgepole pine at the high CR. In all other cases, the lathe panels had least TS.

Part III -- Flaking Alternatives for High Density Species

Bending Strength (MOR)

At the target density of 52.6 pcf, type of flaker, resin content, and species affected bending strength. The 3% addition of resin resulted in an 18% strength increase for initial condition (table 5). Panels with high resin content retained 73% of their initial bending strength after AA; panels with low resin content retained only 65% of their initial bending strength after AA.

Since the bending strengths of panels of the two species were significantly different, the panels of the two species were fabricated at different CR's; thus, an analysis of the effect of CR on bending strength for different flaker-species combinations was possible (table 6, fig. 14). Besides the 52.6 pcf density, red oak panels were targeted to be made at 47.6 pcf and hickory panels at 57.6 pcf. Although the fabrication densities differed from the 52.6 pcf by only 5 pcf, a linear relationship over the plotted CR range was assumed.

The lathe-flake panels were usually strongest for the two species and both test conditions (table 6). The ring-flake panels usually were next strongest. Slopes of disk- and ring-flake panels were similar (fig. 14). Drum-flake panels had steep slopes and were usually weakest at low CR, but their strength approached that of lathe-flake panels at high CR.

Hickory panels were stronger than red oak panels at equivalent CR's and had steeper slopes. At equivalent panel densities, e.g., 52.6 pcf, red oak panels were usually slightly stronger than hickory panels.

Modulus of Elasticity (MOE)

The average MOE's for panels of the four flakers fabricated at 52.6 pcf ranged from 748,000 to 848,000 psi at initial test condition, and from 515,000 to 628,000 psi after AA (table 5). The MOE's of drum-flake panels were lowest among flakers for initial and AA conditions; lathe panels generally had the highest MOE for the two species and both test conditions (fig. 15).

Resin content significantly affected MOE, but panels with 8% resin content also were denser than those with 5% resin content (table 5). Boards with high resin content had a specific modulus (MOE/density) that was 8% higher than panels with low resin content; moreover, the panels with high resin content retained a higher proportion of their strength after AA than those with low resin content.

Resin content and species were significantly related to MOE of lathe-flake panels under both test conditons. Initial strength of ring-flake and disk-flake panels varied with species; strength of these panels after AA varied only with resin content. Using average resin content, species and species-flaker effects were obtained for a CR range (fig. 15). At an equivalent CR, hickory panels were stiffer than red oak panels. Also, the average slope of the four flakers for the hickory panels was steeper for both test conditions than the average slope of the red oak panels. Disk-flake panels of red oak, however, had a steeper slope than hickory panels at initial condition. After AA, ring- and lathe-flake panels of red oak had steeper slopes than the corresponding hickory panels.

Internal Bond (IB)

At 52.6 pcf the ring-flake panels had highest IB under all circumstances except for panels fabricated at 5% resin content and exposed to accelerated aging (fig. 16). At the low resin content after AA the range of the IB for the four flakers was only 7 psi. The IB's of the disk, lathe, and drum panels were similar, except for the lathe-flake panel at 8% resin content under initial conditions.

Although red oak panels had a higher IB than hickory panels at equivalent densities, IB of hickory panels generally exceeded that of red oak panels at equivalent CR's (table 6, fig. 17). Panels made of ring flakes had highest initial IB's for both species over the range of CR's.

Linear Expansion (LE)

In all cases, the OD-VPS values for LE were highest, followed by the 30 to 90% RH values, and then the 24-hour WS (tables 5 and 7). For all three tests the only factor that was significant by itself was flaker type. In most panels additional resin did not decrease LE. Red oak and hickory fabricated at approximately 52.6 pcf had equivalent LE's, but generally, over the CR range, red oak had a slightly lower LE than hickory (fig. 18).

The drum-flake panels had an LE that was either uniform or that decreased with increasing CR for 30 to 90% RH and OD-VPS (fig. 18). A decrease also occurred for disk-flake panels of red oak under the 30 to 90% RH test. At high CR, the drum-flake panels had the lowest LE. The ring- and lathe-flake panels had similar

Table 5.--Average strength and dimensional stability properties for red oak and hickory panels fabricated at a target density of 52.6 pcf with flakes cut from four flakers

	Panel density at 50% RH	MOR		MOE		IB		Linear expansion			Thickness swell		
		INIT[1]	AA[1]	INIT	AA	INIT	AA	30-90% RH	24-HR WS[1]	OD-VPS[1]	30-90% RH	24-HR WS	OD-VPS
	pcf	----psi---		--1000 psi--		----psi----		----------	----------Percent	----------	----------	----------	----------
Overall	52.4	6641	4586	793	564	167	34	.20	.03	.30	12.9	10.5	28.9
Flaker													
Ring	51.3	6601	4537	756	561	219	44	.18	.03	.32	13.5	14.4	33.0
Disk	52.7	6277	4379	820	552	129	30	.23	.02	.34	11.7	9.0	28.4
Lathe	53.3	7604	5263	848	628	167	29	.21	-.01	.26	9.9	8.4	24.2
Drum	52.2	6084	4164	748	515	154	33	.17	.06	.29	16.5	10.5	30.1
Species [2]													
RO	52.2	7009	4789	864	605	175	35	.19	.03	.30	12.0	8.9	28.2
HI	52.5	6274	4383	722	523	160	33	.20	.03	.31	13.8	12.2	29.7
Resin %													
5	51.7	6091	3944	757	514	138	22	.20	.02	.31	14.3	12.6	33.9
8	53.0	7192	5228	829	614	196	46	.20	.03	.30	11.4	8.5	23.9

1/ Initial = 50% RH test condition. AA = after acclerated aging. 24-HR WS = 24-hour water soak. OD-VPS = ovendry vacuum-pressure soak

2/ RO = Red oak, HI = Hickory

Table 6.--Strength properties of red oak and hickory panels made from flakes cut on four types of flakers

Flaker	Species[1]	Panel density at 50% RH	Bending strength Initial[2]	Bending strength AA[2]	Modulus of elasticity Initial	Modulus of elasticity AA	Internal bond Initial	Internal bond AA
		---pcf---	----psi----		-----1000 psi-----		---- psi----	
Ring	RO	46.4	5393	3758	697.7	485.9	168	37
		50.9	6590	4462	799.0	578.6	218	40
	HI	51.7	6634	4613	713.6	543.1	221	47
		55.0	7347	5103	821.1	589.0	232	39
Disk	RO	48.4	5416	3876	764.6	494.0	75	28
		52.9	6715	4559	899.7	574.5	108	23
	HI	52.6	5834	4198	740.5	528.6	150	37
		56.7	6756	4821	792.6	600.3	160	36
Lathe	RO	48.6	6625	4307	800.9	572.9	174	23
		53.3	8070	5470	902.7	677.0	205	30
	HI	53.2	7138	5057	792.4	579.7	128	27
		56.0	8206	5527	863.4	609.2	177	30
Drum	RO	49.4	5409	3906	744.6	538.0	122	20
		51.7	6662	4664	854.2	589.9	168	45
	HI	52.7	5507	3664	641.4	441.0	140	22
		55.1	6849	4548	772.5	539.5	177	27

1/ RO = Red oak, HI = Hickory.

2/ Initial = 50% RH, AA = After accelerated aging.

Table 7.--Oimensional stability properties of red oak and hickory panels made from flakes cut on four types of flakers

Flaker	Species[1/]	CR[2/]	Linear Expansion, 30-90% RH	Linear Expansion, 24-HR WS[3/]	Linear Expansion, OD-VPS[3/]	Thickness swell, 30-90 % RH	Thickness swell, 24-HR WS	Thickness swell, OD-VPS
			Percent					
Ring	RO	1.21	.16	.08	.30	14.4	15.7	32.1
		1.33	.18	.00	.31	14.1	11.7	34.1
	HI	1.13	.19	.08	.33	12.9	17.1	31.9
		1.20	.22	.06	.42	10.4	19.3	34.9
Oisk	RO	1.26	.22	.02	.28	12.1	10.2	27.4
		1.38	.19	.01	.31	10.8	8.0	29.0
	HI	1.15	.27	.02	.38	12.6	9.8	27.9
		1.24	.31	.01	.39	11.5	7.8	30.1
Lathe	RO	1.27	.17	.04	.24	11.7	9.1	23.2
		1.39	.22	.02	.28	8.8	7.5	24.5
	HI	1.16	.21	-.04	.24	11.1	9.2	23.9
		1.22	.24	.00	.30	12.2	8.2	24.7
Drum	RO	1.29	.19	.09	.30	15.5	9.6	28.1
		1.35	.20	.06	.27	14.5	8.6	25.3
	HI	1.15	.20	.05	.31	17.8	10.2	37.9
		1.20	.14	.06	.31	18.5	12.4	35.0

1/ RO = Red Oak, HI = Hickory.

2/ CR = Compression ratio

3/ 24 HR WS = 24-hour water soak; OO-VPS = ovendry-vacuum pressure soak.

Table 8.--Strength and dimensional stability properties of panels made from flakes of five species. Flakes were produced on four flakers and panels were pressed to a 1.25 compression ratio

	Density at 50% RH	MOR INIT[1]	MOR AA[1]	MOE INIT[1]	MOE AA[1]	IB INIT	IB AA	Linear Expansion 30-90% RH	Linear Expansion 24-HR WS[1]	Linear Expansion OO-VPS[1]	Thickness Swell 30-90% RH	Thickness Swell 24 HR WS	Thickness Swell OD-VPS
	pcf	--- psi---		1000 psi		--- psi---		Percent					
Overall	42.6	5016	3825	647	499	105	27	0.17	0.07	0;27	13.9	15.8	27.4
Flaker													
Ring	41.1	4803	3684	610	480	132	34	.16	.09	.31	14.4	19.0	29.5
Oisk	42.9	4988	3934	665	530	96	33	.20	.05	.28	13.0	13.6	26.3
Lathe	43.1	5565	4083	685	514	104	21	.15	.04	.22	12.1	13.2	23.5
Orum	43.3	4706	3600	629	473	87	20	.16	.09	.27	15.9	17.2	30.2
Species													
LP	30.9	3717	3252	525	458	58	23	.12	.08	.21	14.3	19.4	24.2
LL	39.4	4226	3475	579	477	70	31	.12	.09	.22	13.9	21.0	24.8
SG	39.8	4136	3438	567	455	72	22	.17	.08	.27	14.2	15.9	28.3
RO	48.2	5711	3962	752	523	135	27	.18	.06	.28	13.4	11.1	27.8
HI	55.7	7290	4999	812	585	189	33	.24	.03	.35	13.5	11.4	31.9
Resin %													
5	42.2	4643	3415	623	463	86	16	.16	.06	.26	15.4	18.0	31.6
8	43.0	5389	4235	671	536	123	39	.17	.08	.28	12.3	13.5	23.2

1/ INIT = 50% RH test condition.
AA = after accelerated aging.
24-HR WS = 24=hour water soak.
OD-VPA = ovendry vacuum-pressure soak.

2/ LP = lodgepole pine, LL = loblolly pine, SG= sweetgum, RO = red oak, HI = hickory.

LE's that were usually lower than those of the drum- or disk-flake panels.

Thickness Swell (TS)

Unlike with linear expansion, resin content, species, and flaker significantly affected TS for the three test conditions. Interactions affected TS for the 30 to 90% RH and OD-VPS. In all cases, the OD-VPS cycle caused the most TS.

Lathe- and disk-flake panels had least TS for all three tests (table 5). Except for the 30 to 90% RH cycle, ring-flake panels had greatest TS. The TS of ring-flake panels from the WS exceeded that from the 30 to 90% RH cycle.

Red oak panels fabricated at a density of 52.6 pcf had less TS than hickory panels (table 5). Under the OD-VPS evaluation, red oak panels yielded lower TS and a lower rate of TS change per CR change than hickory panels of all flake types (table 7, fig. 18). With both species, TS of lathe-, disk-, and ring-flake panels increased with CR for the OD-VPS cycle; TS of drum-flake panels decreased.

The 30 to 90% RH environment caused a slight decrease in TS with increasing CR for all red oak panels and for disk- and ring-flake hickory panels. For the lathe- and drum-flake panels of hickory, low CR yielded low TS.

Except for disk-flake panels subjected to 30 to 90% RH and ring-flake panels subjected to WS, resin content was a significant factor for the individual flakers. Increasing resin decreased TS an average of 2.9, 4.1, and 10% for 30 to 90% RH, WS, and OD-VPS. The largest decrease occurred for ring-flake panels followed by drum-, lathe-, and disk-flake panels (fig. 19). Lathe-flake panels had the lowest TS for all test conditions at equivalent resin contents.

Part IV.-- Selecting a Flaker: Comparing the Five Species

Based on observed means of panels fabricated at 12.5 CF, this section presents major trends and effects to allow an assessment of the flakers.

Bending Strength (MOR)

Panels of lathe flakes had the highest average strength followed by disk-, ring-, and drum-flake panels for initial (50% RH) and accelerated aging test conditions (table 8). Accelerated aging lowers bending strength of panels from all the flakers. Lathe-flake panels were strongest for the species with the lowest specific gravity (lodgepole pine) and the two species with the highest specific gravities (table 9). Loblolly pine and sweetgum panels made from disk flakes were strongest. Although the lathe- and disk-flake panels were strongest overall, each also had a panel of one species that was weakest, i.e., hickory for the disk and loblolly pine for the lathe.

Increasing resin content from 5 to 8% raised MOR an average of 16%; after accelerated aging, MOR was 24% higher for the 8% resin content than for the 5%. By increasing resin content, bending strength for lathe- and disk-flake panels increased 14.3% and 10.8%, while the ring- and drum-flake panels had a 19.0% increase. Except with lathe-flake panels, the greatest strength increase caused by increasing resin content occurred with hickory; lodgepole pine had the largest strength increase for the lathe-flake panels.

Modulus of Elasticity (MOE)

The MOE trends were similar to those of bending strength. An increase in resin content increased MOE of all except lathe panels. At the higher resin content, both the ring- and drum-flake panels yielded 10.4% increase in MOE, but the disk had only an 8.0% increase. The average MOE increase of the lathe-flake panels was smallest (2.3%), but lodgepole pine panels fabricated with lathe flakes had the greatest (18.2%) increase with increased resin content.

Panels of different species fabricated at the target compression ratio (CR) of 1.25 did not produce the same MOE. Hickory, then red oak, had the highest average MOE's and the highest MOE for each flaker (table 9). The lathe produced the stiffest panel for high and low density species and the disk for the two intermediate species (sweetgum and loblolly pine). The data indicated that as species density increases, the CR can decrease to obtain equivalent properties. For instance, hickory, fabricated at the lowest CR (1.21), was stiffest. Hickory and red oak could have been fabricated at even lower CR's to obtain stiffness values equal to those of the other species.

Internal Bond (IB)

The ring-flake panels had the highest IB for 50% RH and after accelerated aging (table 8). At 50% RH, the ring-flake panels' IB was 28 psi higher than the lathe-flake panels' IB, which was next highest. The IB's of the ring- and disk-flake panels after aging differed by only one psi and were greater than the IB's of the lathe-flake and drum-flake panels.

As species density increased, initial IB increased from 58 psi to 189 psi (table 8), indicating that an individual IB-CR relationship may exist for each species. After accelerated aging, however,

Table 9.--Strength properties of panels made from flakes of five species. Flakes were cut on four types of flakers and panels pressed to a 1.25 compression ratio

Flaker	Species[1/]	Bending strength Initial[2/]	Bending strength AA[2/]	Modulus of elasticity Initial[2/]	Modulus of elasticity AA[2/]	Internal bond Initial[2/]	Internal bond AA[2/]
		psi	psi	1,000 psi	1,000 psi	psi	psi
Ring	LP	3,141	2,837	432.8	390.7	68.6	35.3
	LL	4,200	3,569	555.0	483.8	96.6	44.8
	SG	3,936	3,151	543.1	449.9	82.7	15.4
	RO	5,393	3,758	697.7	485.9	168.0	37.3
	HI	7,347	5,103	821.1	589.0	244.2	39.2
Disk	LP	3,358	3,013	514.4	462.0	70.6	33.3
	LL	4,609	3,825	603.2	527.7	82.3	33.3
	SG	4,803	4,133	649.2	568.2	92.2	33.7
	RO	5,416	3,876	764.6	493.9	75.2	27.8
	HI	6,756	4,821	792.6	600.3	159.4	36.2
Lathe	LP	4,738	4,189	615.2	555.0	47.8	10.9
	LL	4,026	2,973	568.5	417.7	59.7	24.9
	SG	4,231	3,419	575.6	416.1	60.0	17.6
	RO	6,625	4,307	800.9	572.9	174.1	22.8
	HI	8,206	5,526	863.4	609.2	176.9	30.1
Orum	LP	3,631	2,967	537.2	425.0	43.2	11.9
	LL	4,068	3,532	591.1	478.2	42.3	21.3
	SG	3,573	3,048	498.1	385.9	52.3	21.4
	RO	5,409	3,906	744.6	538.0	122.1	20.4
	HI	6,849	4,548	772.4	539.5	176.6	26.8

1/ LP = lodgepole pine, LL = loblolly pine, SG = sweetgum, RO = red oak, HI = hickory.

2/ Initial = 50% RH; AA = after accelerated aging.

Table 10--Dimensional stability properties of panels made from flakes of five species. Flakes were cut on four types of flakers and panels pressed to 1.25 compression ratio

Flaker	Species[1/]	Linear expansion 30-90% RH	Linear expansion 24-HR WS[2/]	Linear expansion OO-VPS[2/]	Thickness swell 30-90% RH	Thickness swell 24-HR WS	Thickness swell OO-VPS
		Percent					
Ring	LP	0.15	0.11	0.26	14.1	18.6	23.6
	LL	.12	.11	.27	14.4	18.9	25.9
	SG	.15	.10	.28	16.1	22.4	31.2
	RO	.16	.07	.30	14.3	15.7	32.0
	HI	.22	.06	.42	12.8	19.3	34.9
Disk	LP	.15	.07	.23	15.1	18.6	24.4
	LL	.13	.07	.23	13.4	17.6	22.2
	SG	.20	.06	.22	13.2	13.9	27.4
	RO	.21	.02	.28	12.1	10.2	27.4
	HI	.31	.02	.39	11.4	7.8	30.1
Lathe	LP	.11	.07	.18	11.9	17.9	20.6
	LL	.11	.07	.17	12.2	20.8	23.3
	SG	.15	.01	.21	12.6	9.9	25.6
	RO	.17	.04	.24	11.7	9.1	23.7
	HI	.23	.00	.30	12.2	8.2	24.7
Orum	LP	.07	.08	.19	15.8	22.5	28.1
	LL	.14	.11	.23	15.6	26.7	27.6
	SG	.18	.14	.33	14.9	17.1	29.1
	RO	.19	.09	.29	15.5	9.6	28.1
	HI	.20	.04	.31	17.7	10.2	37.9

1/ LP = lodgepole pine, LL = loblolly pine, SG = sweetgum, RO = red oak, HI = hickory.

2/ 24-HR WS = 24-hour water soak.
OD-VPS = ovendry vacuum-pressure soak.

high-density species had a much greater drop in IB. The decrease resulted in only an 11 psi IB range among species. These relationships generally held for panels of all species made from individual flakers.

Linear Expansion (LE)

Except for drum-flake panels of lodgepole pine, the 24-hour water soak (WS) condition produced less LE than 30 to 90% RH. The OD-VPS caused more LE than either of the other test conditions for all experimental factors (table 8). Increasing resin content increased LE only 0.01% for the 30 to 90% RH condition and 0.02% for the WS and OD-VPS conditions. The effect of resin content on LE also depended on flaker type.

In general, as species density increased, LE based on OD-VPS and 30 to 90% RH increased, but LE based on WS decreased (tables 8 and 10). If all species are averaged, the lathe-flake panels had the lowest LE values for all three test conditions (table 8). The lathe-flake panels of all species expanded less under OD-VPS than panels made from flakes produced by the other flakers (table 10). Except for red oak panels, lathe-flake boards expanded less under the WS (table 10). However, for 30 to 90% RH, loblolly pine was the only species with lowest LE among lathe-flake panels. Thus, to select the flaker that would yield the least LE, species and test conditions should be considered. But, generally, the lathe was best (less than 0.25% regardless of test conditions).

Thickness Swell (TS)

The largest amount of TS occurred under OD-VPS conditions (table 8). An increase in resin content decreased TS by 3, 5, and 8% for 30 to 90% RH, WS, and OD-VPS conditions. The TS for the ring-flake panels after WS exceeded the TS of drum-flake panels. Otherwise the order of increasing TS for all three conditions was the lathe-, disk-, ring-, and drum-flake panels.

As species density increased, a trend toward increased TS for OD-VPS was evident. In the WS, TS varied inversely with wood density. Under the 30 to 90% RH test, the species displayed a fairly uniform TS, with averages ranging frcm 13.4% for red oad to 14.3% for lodgepole pine. Red oak and hickory TS in the 30 to 90% RH test was higher than in the WS, but the reverse occurred for the other species. Generally, these trends were evident for each flaker (table 10). Other than that, the lathe had the least TS for the three hardwoods based on OD-VPS, the best flaker for a particular species to yield a low TS depended on the test conditions.

Summary Comparisons

The densities of the species evaluated ranged from 23.7 pcf for lodgepole pine to 45.8 pcf for hickory. A compression ratio of 1.25 was attempted, but the actual compression ratio for the panels generally decreased as species density increased. In general, panels of species with high densities had better MOR, MOE, and IB properties than less dense species. However, the high density species generally had a greater loss in these properties after aging. This loss may indicate bonding difficulties for high density species or may be caused by anatomical characteristics.

One can rank the flakers based on data for the combined species. Properties were ranked from 1 (best) to 4, then added to obtain a total value. The two comparisons below are based on different test environments (numbers in parentheses represent the property rankings). The data indicate that the disk and lathe flakers yielded flakeboards with similar properties that, overall, were better than the properties of panels from the ring and drum flakers.

No flaker consistently yielded panels with the best properties. If only one species and several properties were selected for analysis, a flaker could be chosen that would yield a panel superior to panels produced by other flakers. Thus, in an area where only one of the species tested here or a species similar to it is available, a flaker could be selected that would be superior to the others.

A. No drastic environmental test:

Flaker	Initial test, psi MOR	MOE	IB	24-hr. W.S.(%) LE	TS	Total value	Final ranking
Ring	(2)4,803	(3)610,000	(1)132	(3)0.09	(4)19.0	13	3
Disk	(2)4,988	(1)665,000	(2) 96	(1) .05	(1)13.6	7	1
Lathe	(1)5,565	(1)685,000	(2)104	(1) .04	(1)13.2	6	1
Drum	(2)4,706	(3)629,000	(4) 87	(3) .09	(3)17.2	15	3

B. Severe environmental test:

Flaker	Initial test, psi MOR	MOE	IB	24-hr. W.S.(%) LE	TS	Total value	Final ranking
Ring	(3)3,684	(3)480,000	(1)34	(4).31	(3)29.5	14	3
Disk	(1)3,934	(1)530,000	(1)33	(2).28	(2)26.3	7	1
Lathe	(1)4,083	(1)514,000	(3)21	(1).22	(1)23.5	7	1
Drum	(3)3,600	(3)473,000	(3)20	(2).27	(4)30.2	15	3

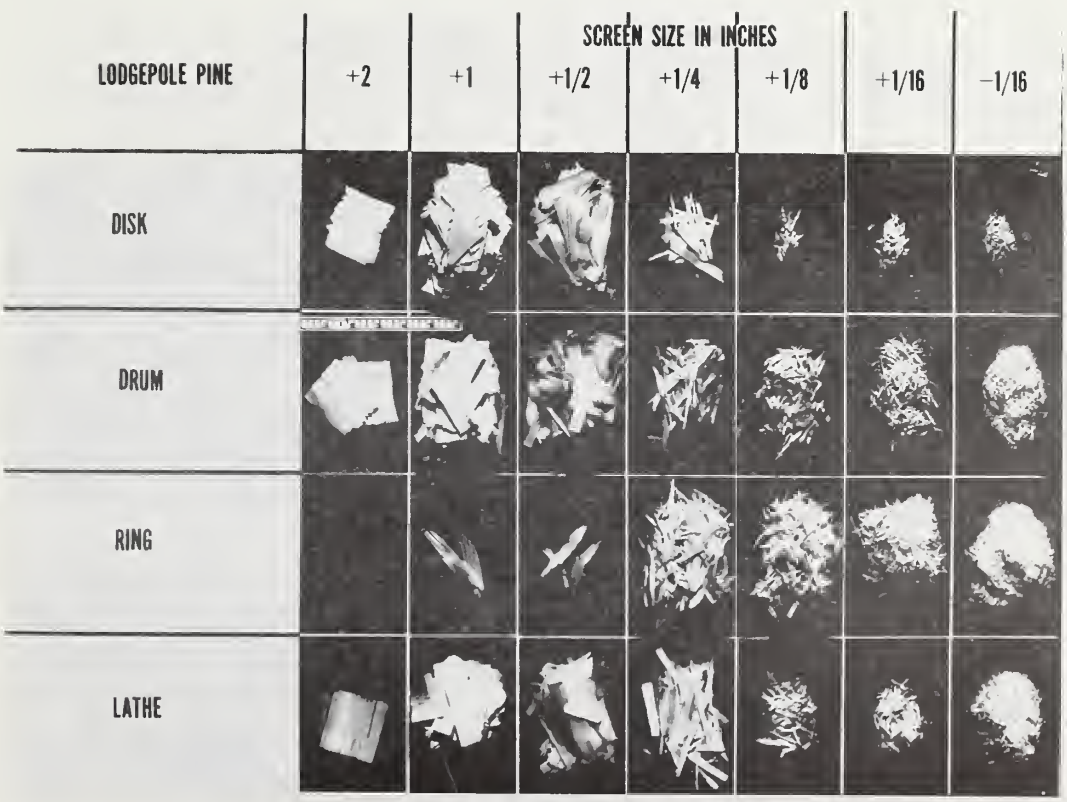


Figure 1. Lodgepole flakes from each of four flakers shown as the weight percentage retained on each screen.

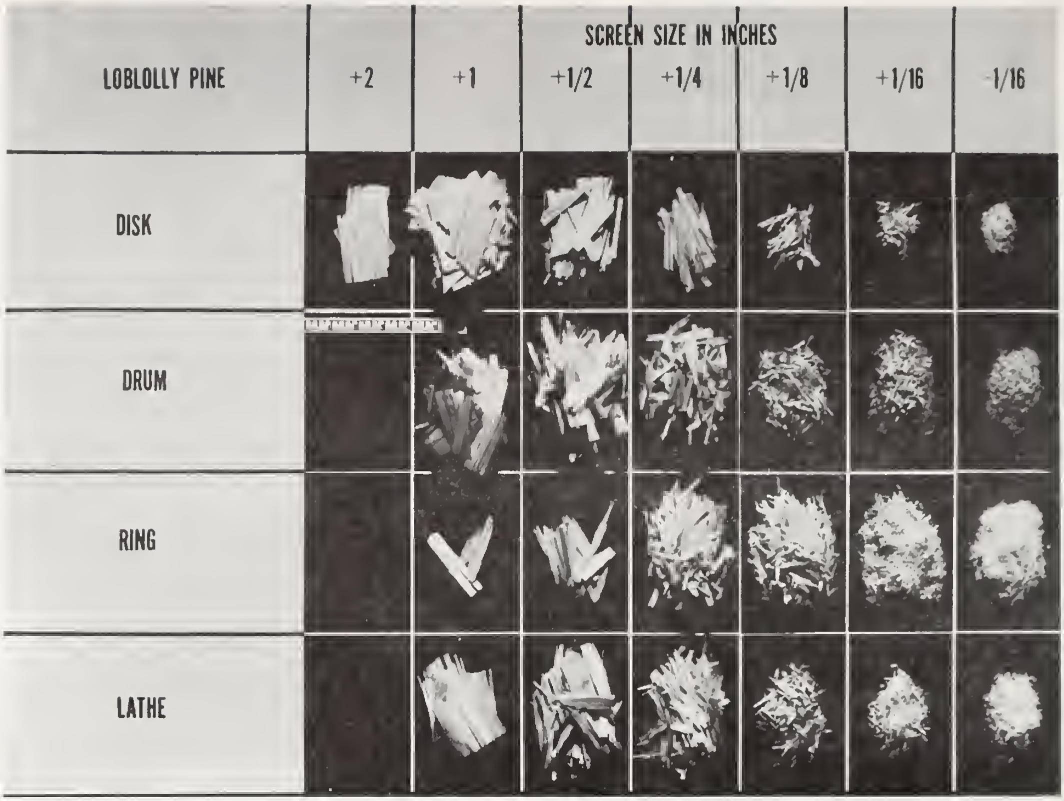


Figure 2. Loblolly flakes from each of four flakers shown as the weight percentage retained on each screen.

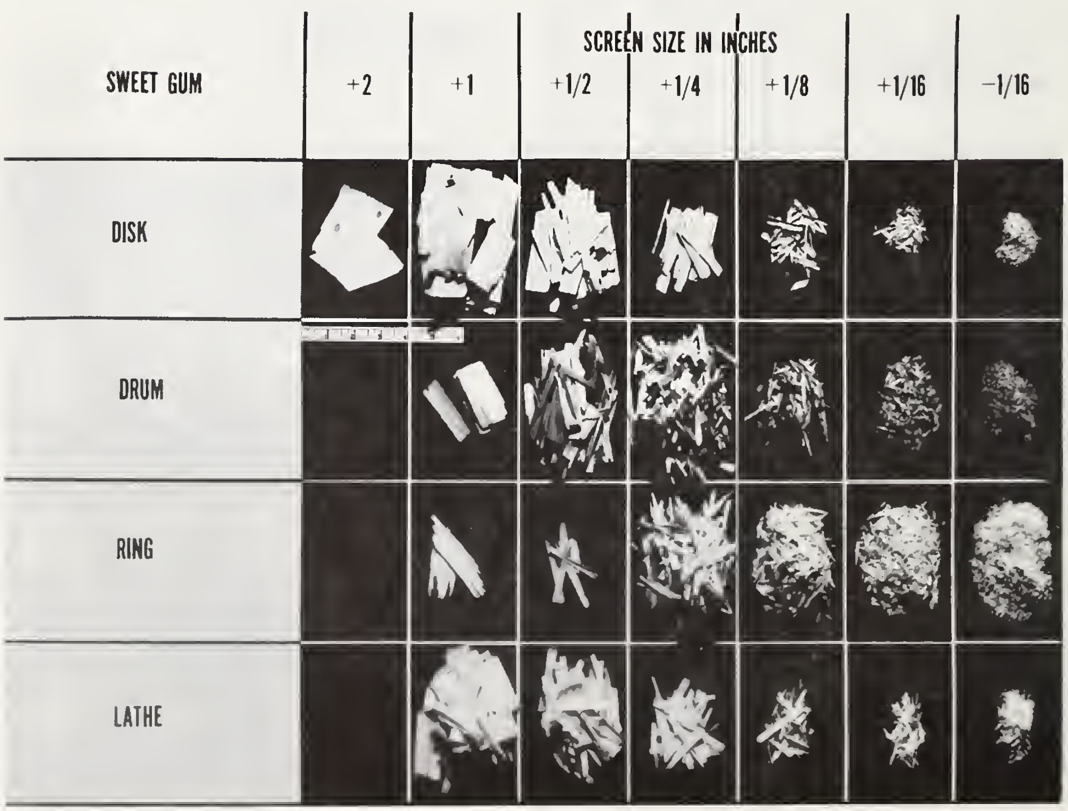


Figure 3. Sweetgum flakes from each of four flakers shown as the weight percentage retained on each screen.

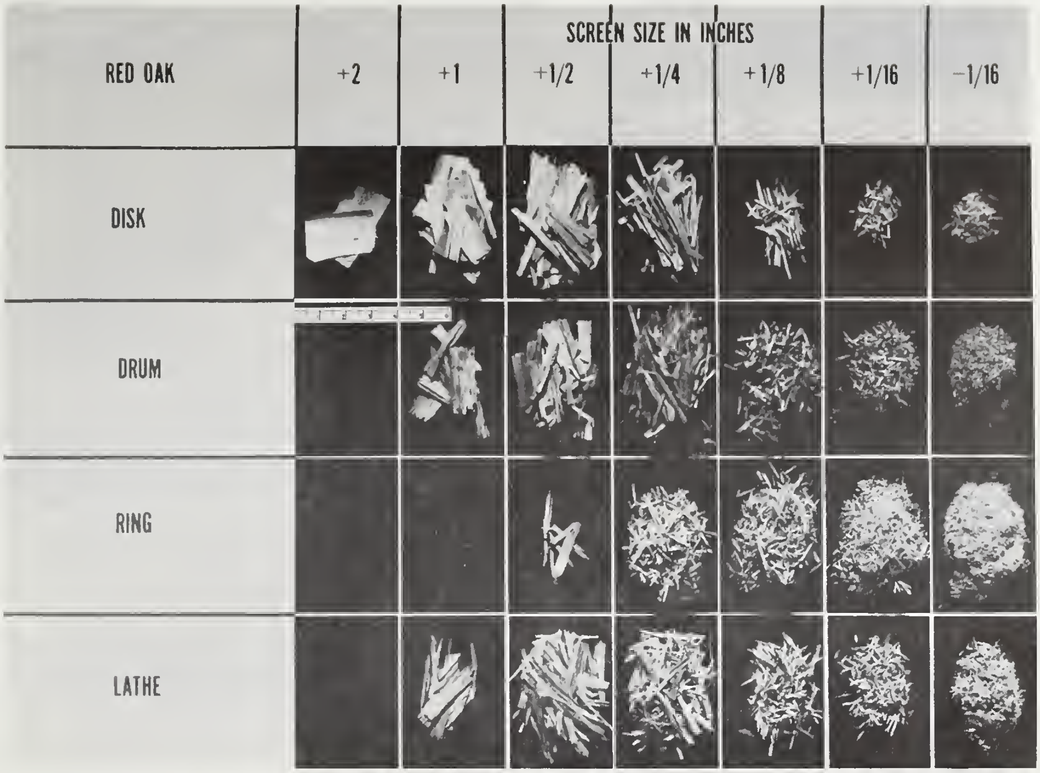


Figure 4. Red oak flakes from each of four flakers shown as the weight percentage retained on each screen.

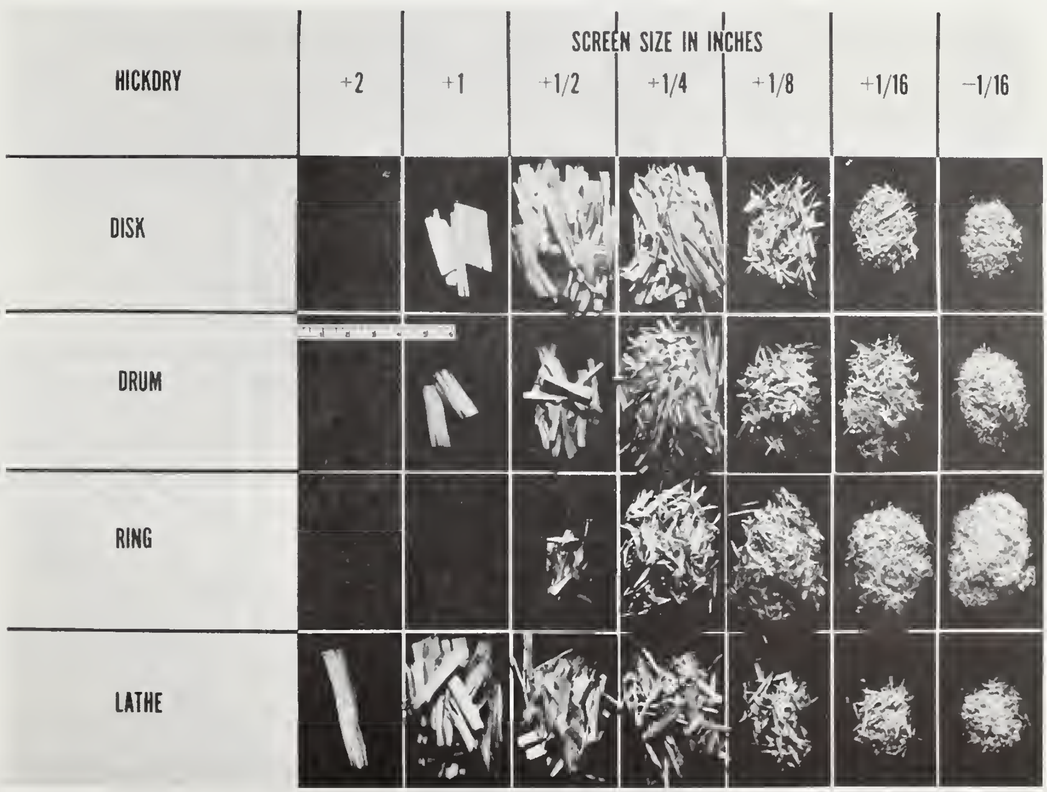


Figure 5. Hickory flakes from each of four flakers shown as the weight percentage retained on each screen.

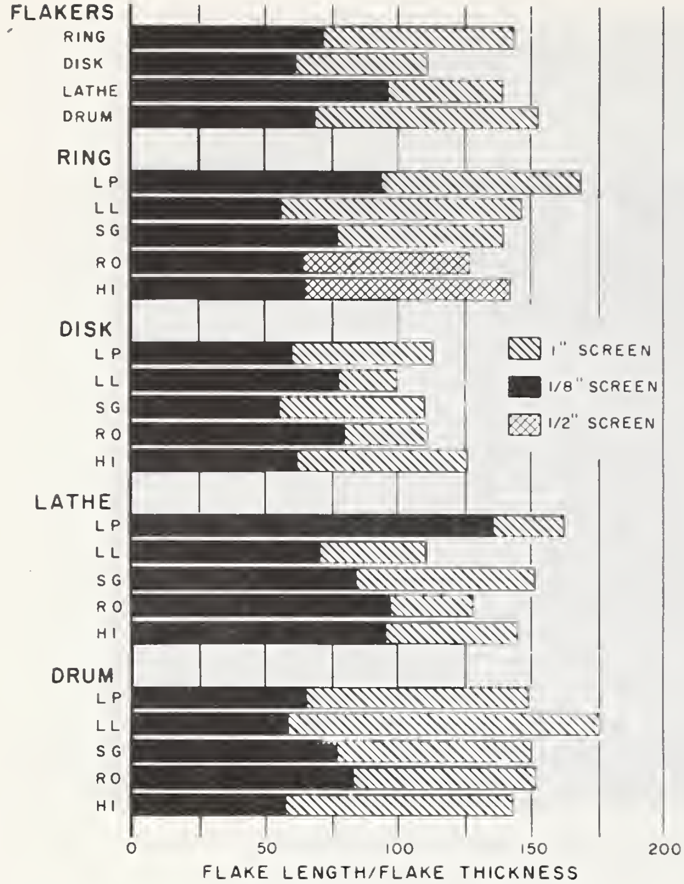


Figure 6. Ratio of flake length to flake thickness for lodgepole pine (LP), loblolly pine (LL), sweetgum (SG), red oak (RO), and hickory (HI) flakes cut on four flakers.

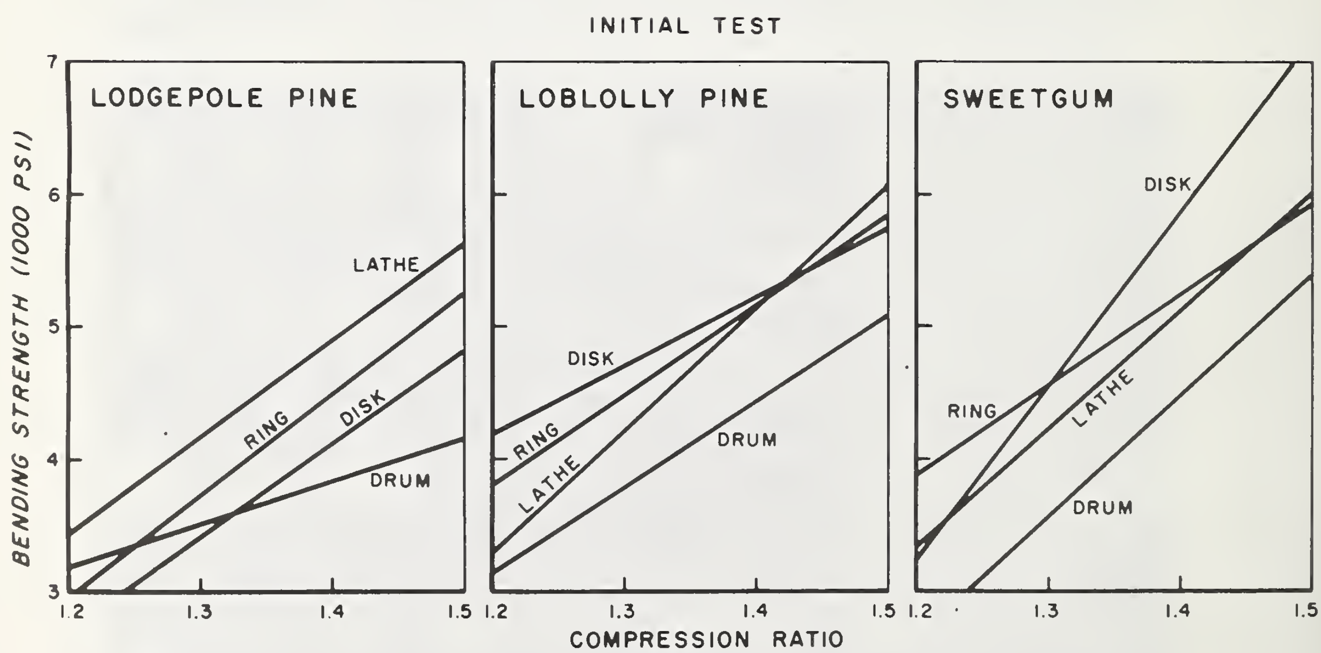


Figure 7. Bending strength and compression ratio relationship at 50% relative humidity for lodgepole pine, loblolly pine, and sweetgum panels made from flakes cut on four flakers.

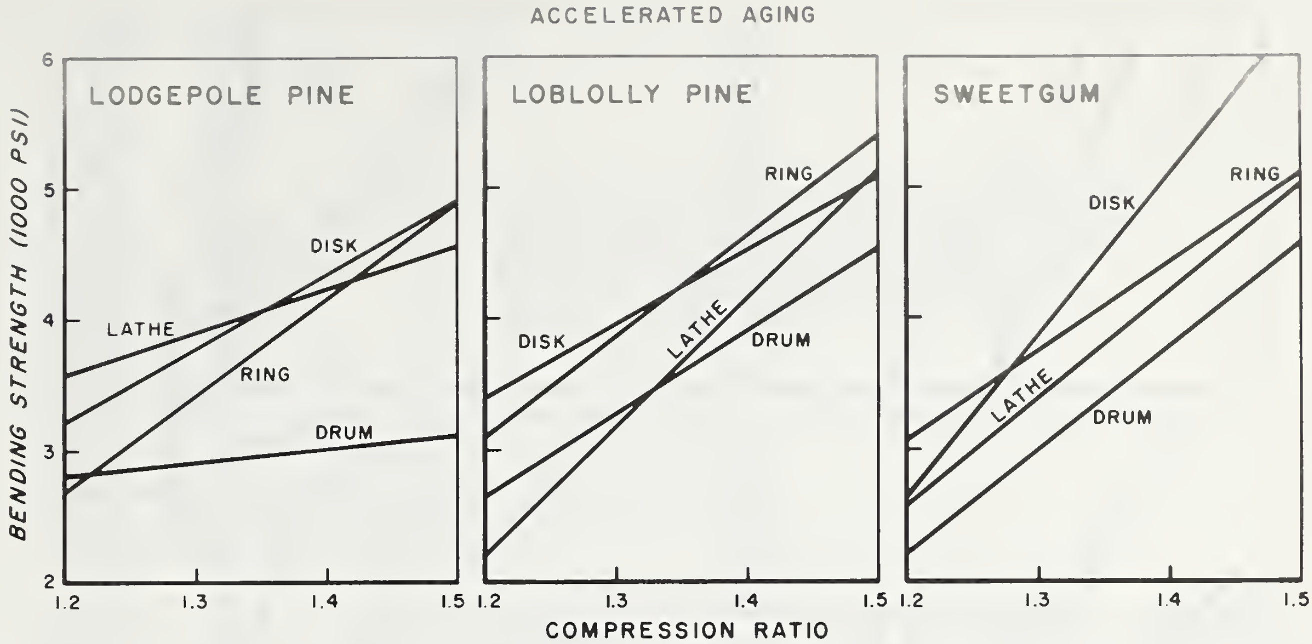


Figure 8. Bending strength and compression ratio relationship after accelerated aging cycle for lodgepole pine, loblolly pine, and sweetgum panels made from flakes cut on four flakers.

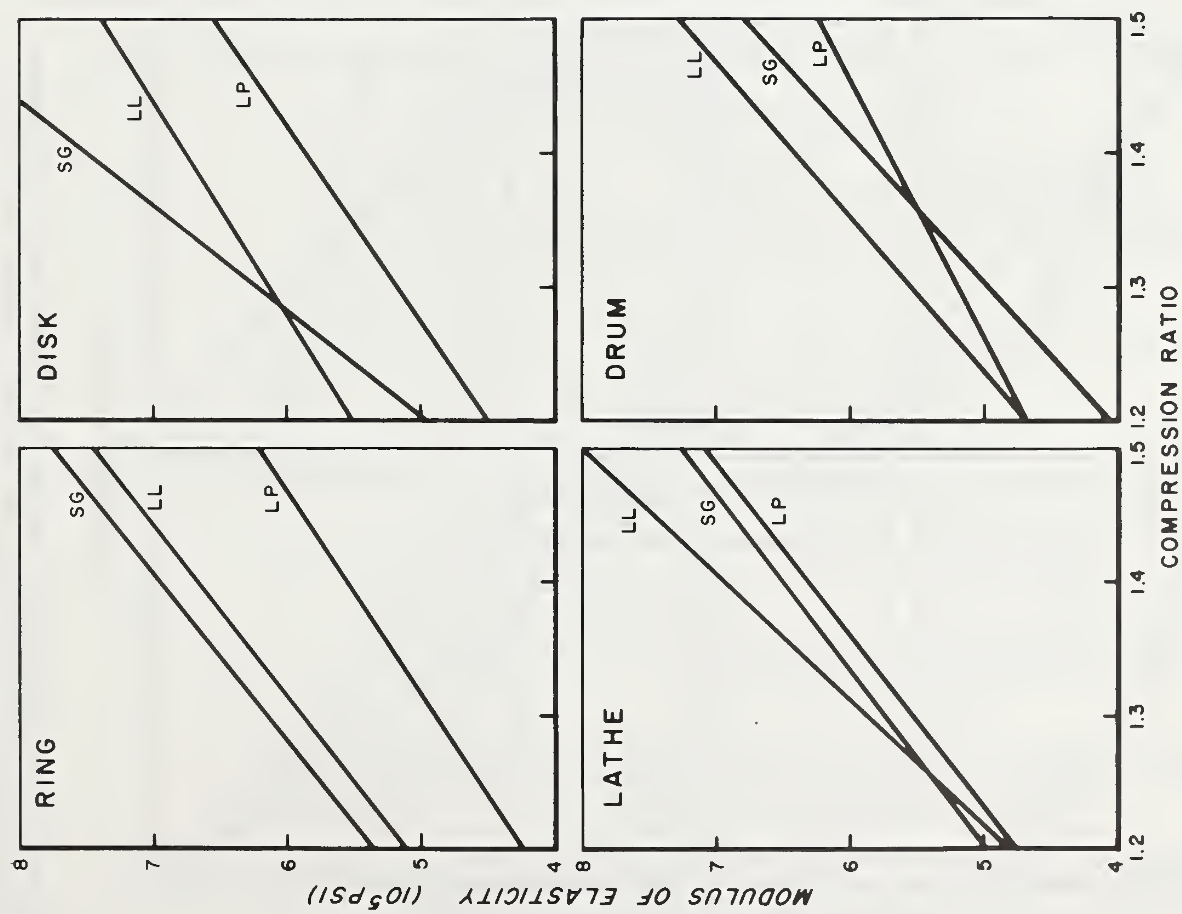


Figure 9. Modulus of elasticity and compression ratio relationship at 50% relative humidity for lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made from flakes cut on four flakers.

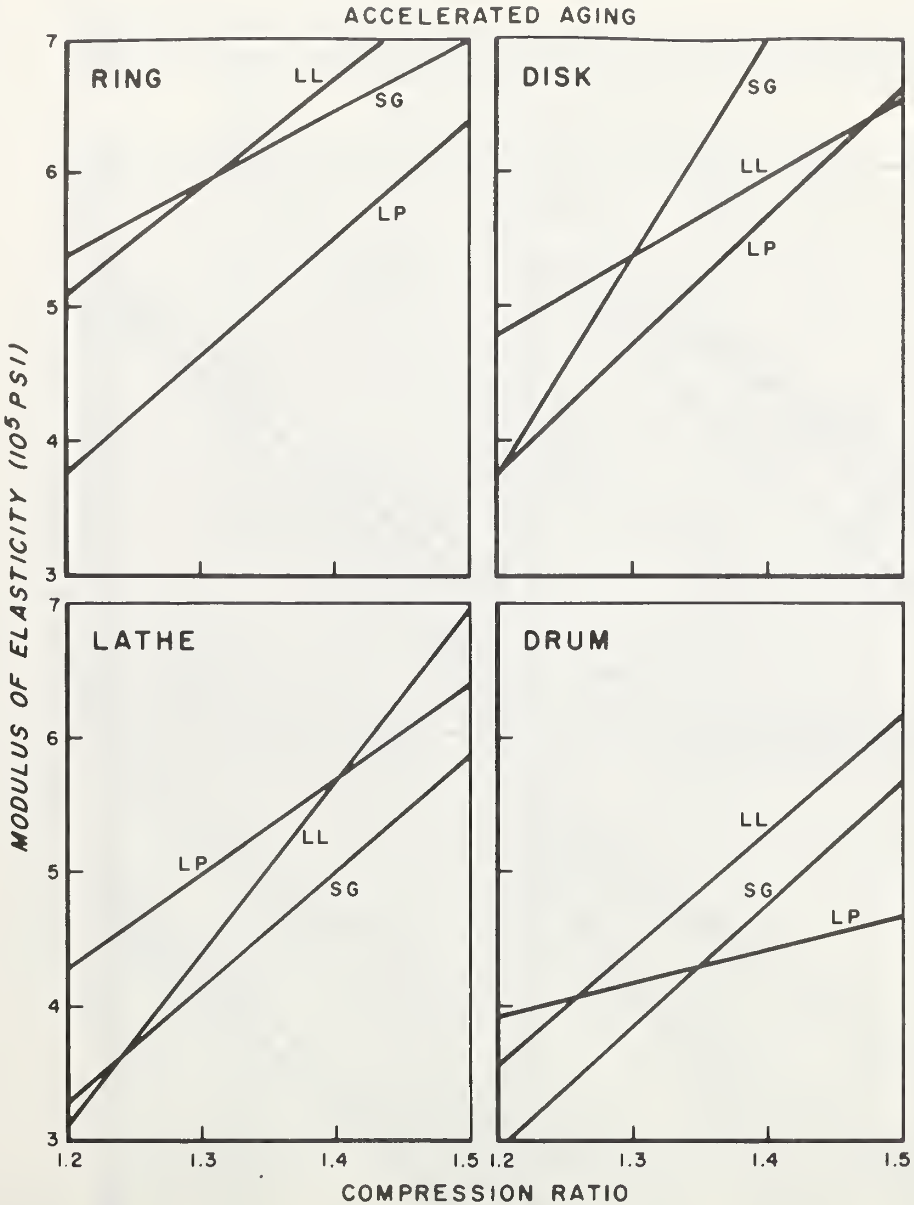


Figure 10. Modulus of elasticity and compression ratio relationship after accelerated aging cycle for lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made from flakes cut from four flakers.

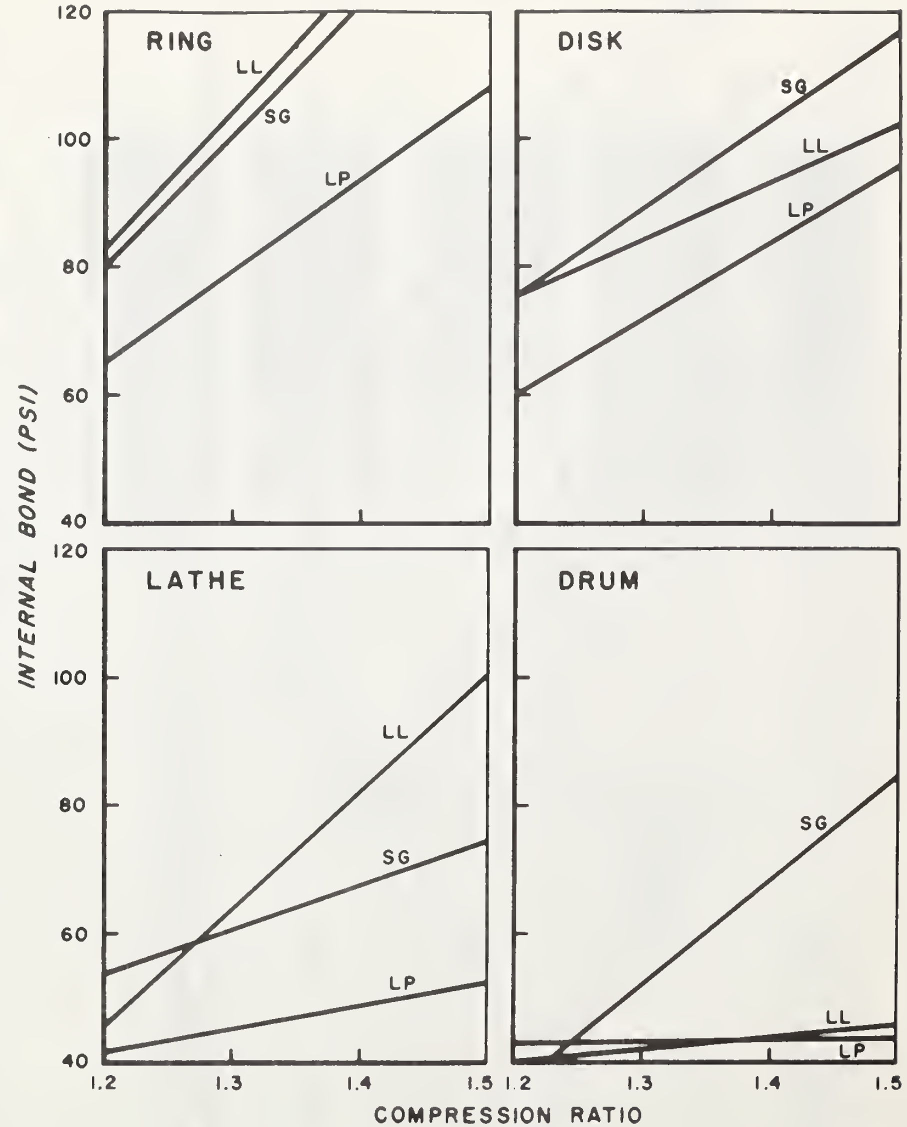


Figure 11. Internal bond and compression ratio relationship at 50% relative humidity for lodgepole pine (LP), loblolly pine (LL), and sweetgum(SG) panels made from flakes cut on four flakers.

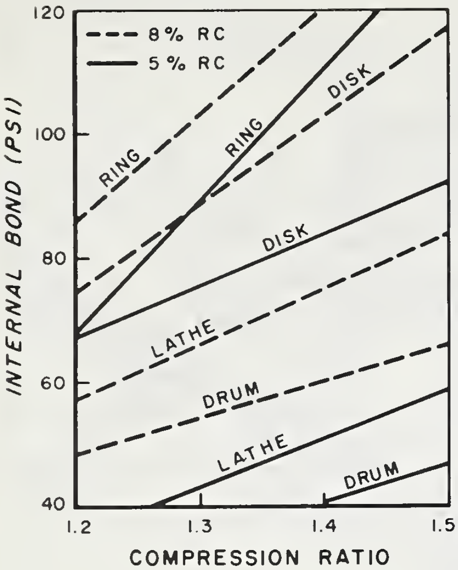


Figure 12. Internal bond and compression ratio relationship at 50% relative humidity for the average of three species--lodgepole pine, loblolly pine, and sweetgum--and two resin contents (5% and 8%). Panels were made from flakes cut on four flakers.

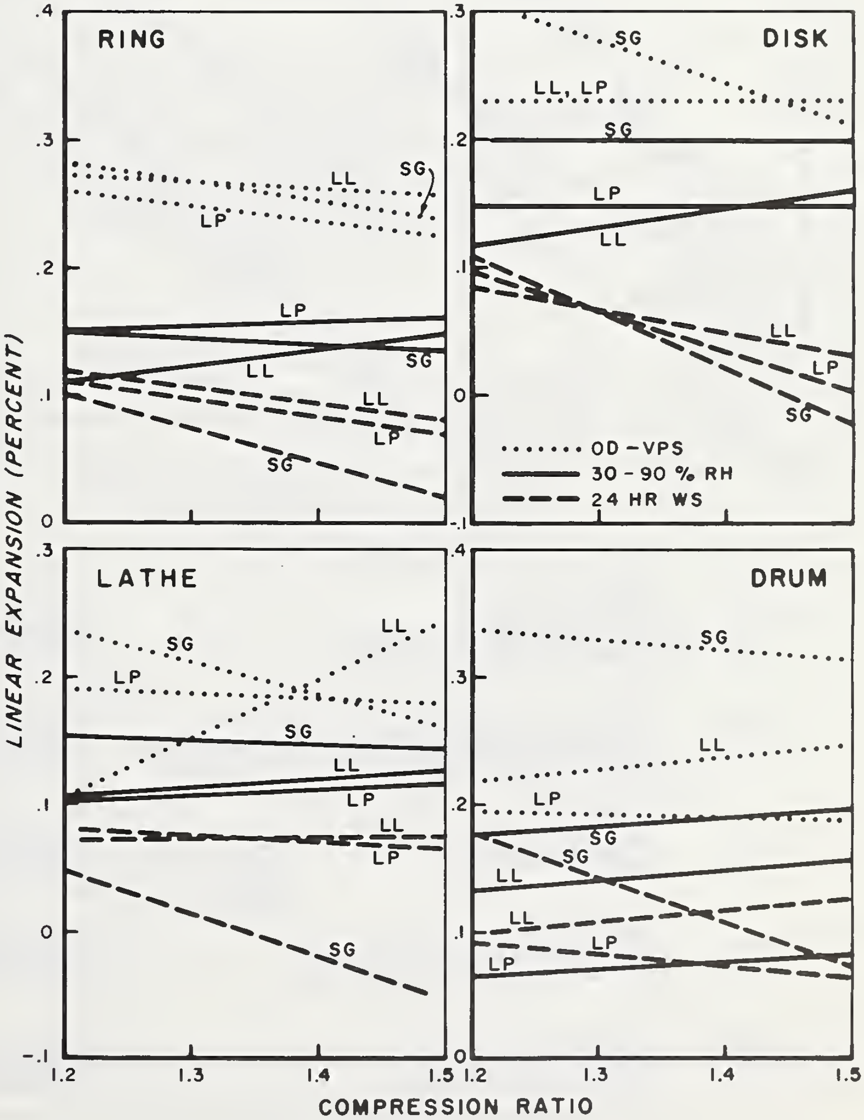
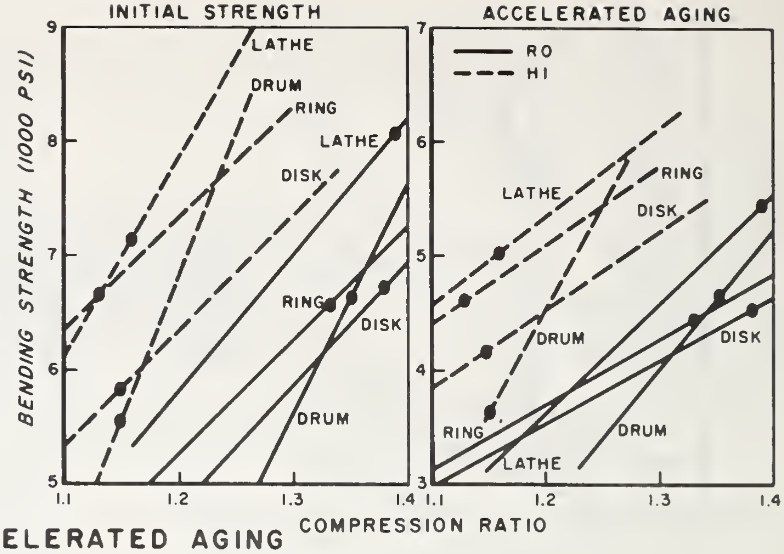


Figure 13. Linear expansion and compression ratio relationship for lodgepole pine (LP), loblolly pine (LL), and sweetgum (SG) panels made with flakes cut on four flakers.

Figure 14. Bending strength and compression ratio relationship for red oak and hickory panels made with flakes from four flakers. Panels fabricated at the target density of 52.6 pcf are accentuated.



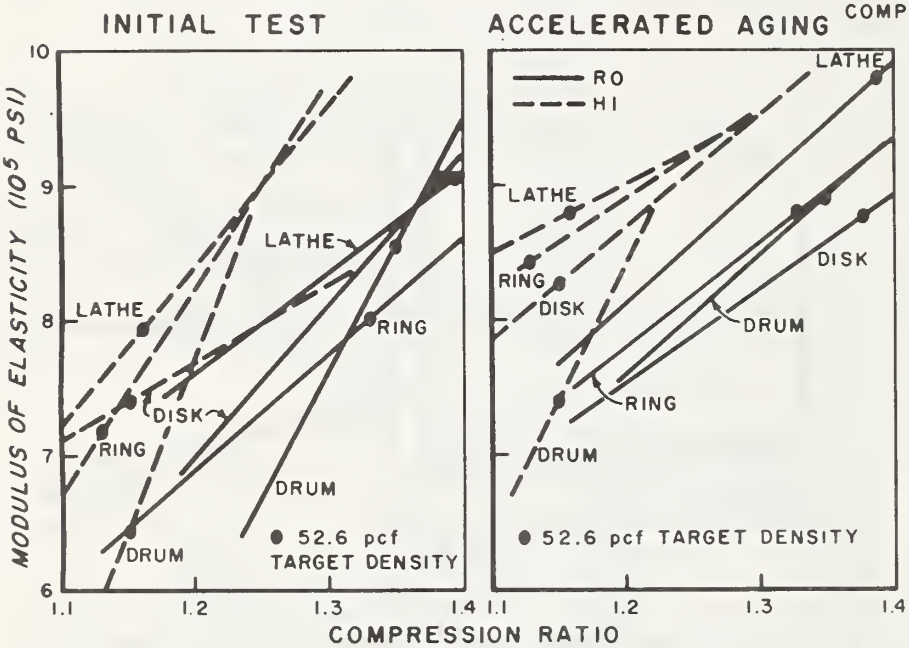


Figure 15. Modulus of elasticity and compression ratio relationship for red oak and hickory panels made with flakes from four flakers. Panels fabricated at the target density of 52.6 pcf are accentuated.

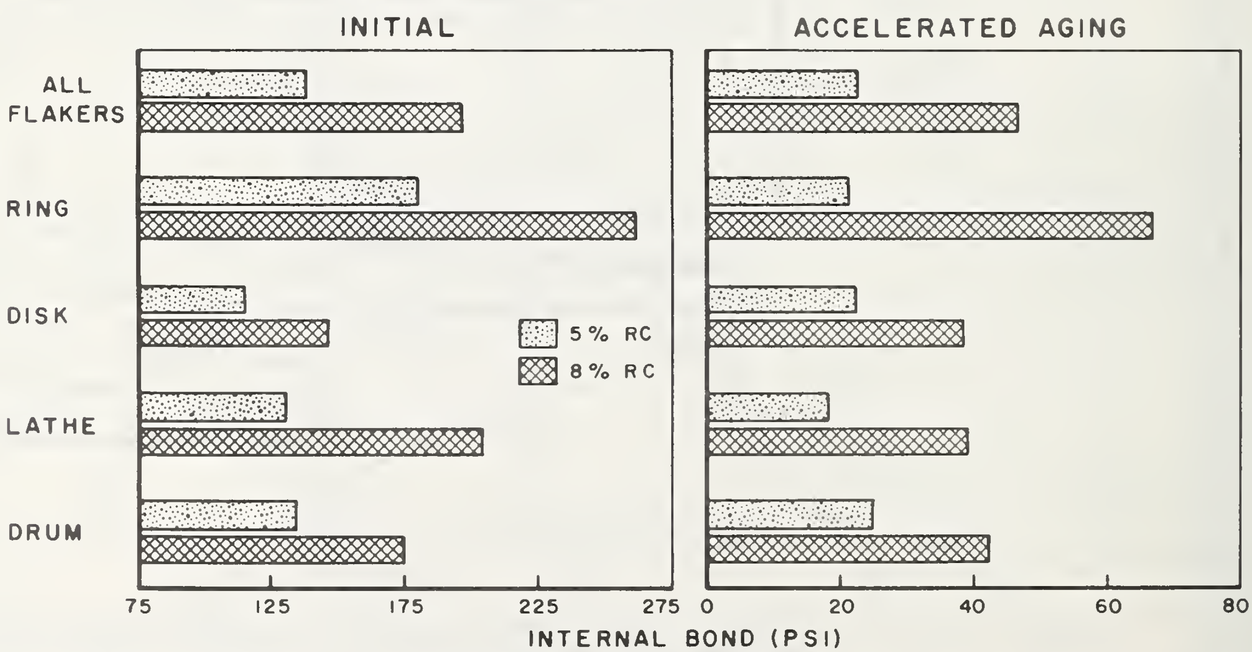


Figure 16. Effect of 5% and 8% resin content on the average internal bond of red oak and hickory panels combined. Panels were fabricated at a target density of 52.6 pcf with flakes generated from four flakers.

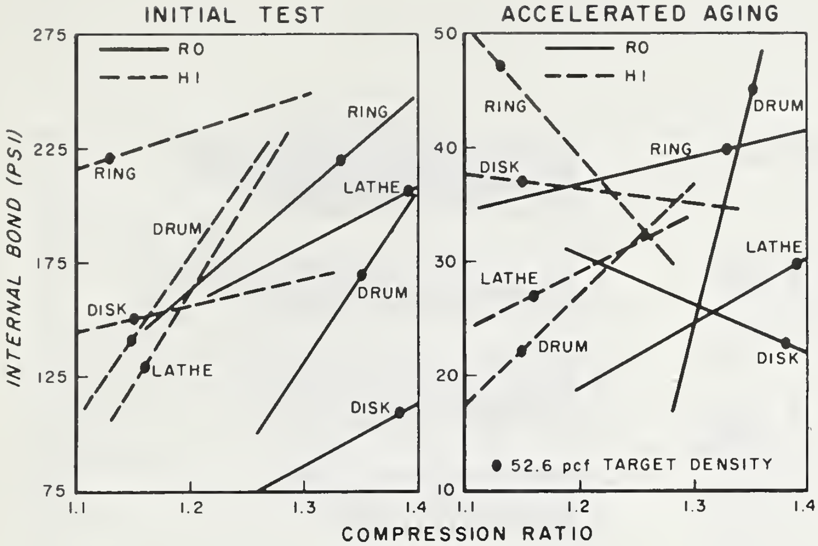


Figure 17. Internal bond and compression ratio relationship for red oak and hickory panels made with flakes from four flakers. Panels fabricated at the target density of 52.6 pcf are accentuated.

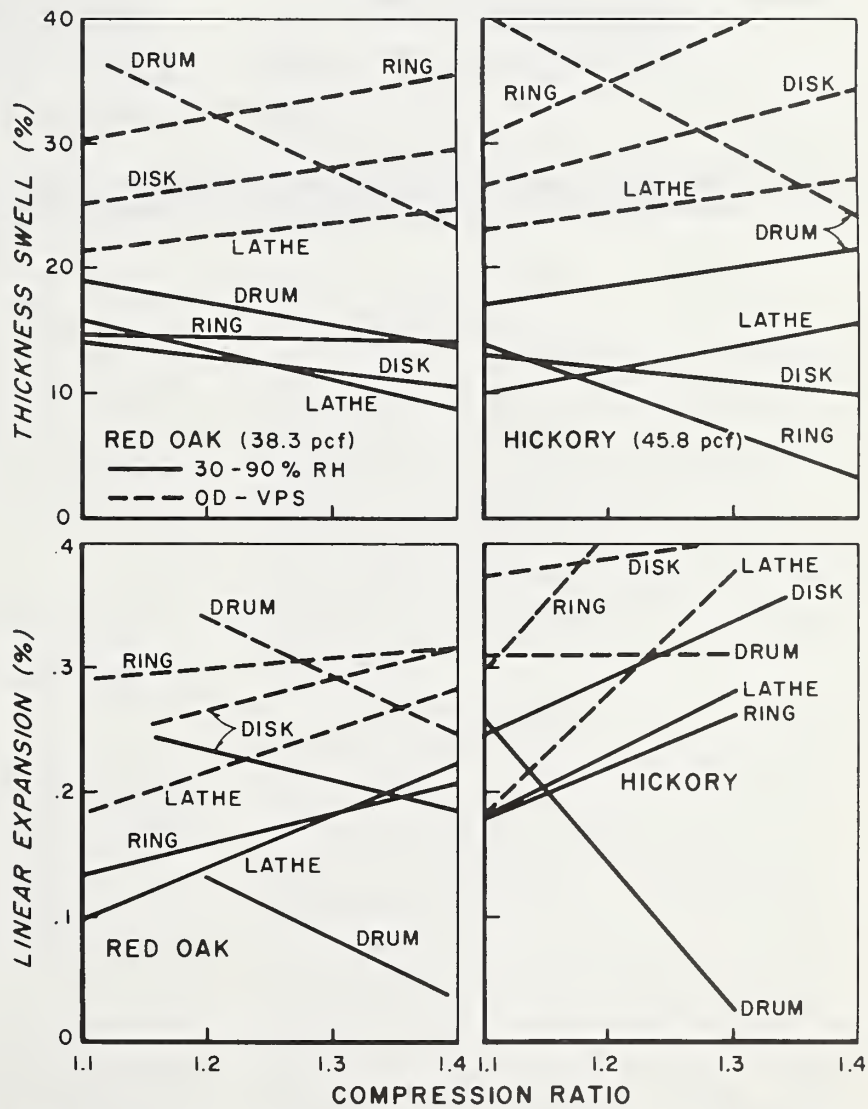


Figure 18. Dimensional properties (linear expansion and thickness swell) and compression ratio relationship for red oak and hickory panels fabricated with flakes from four flakers.

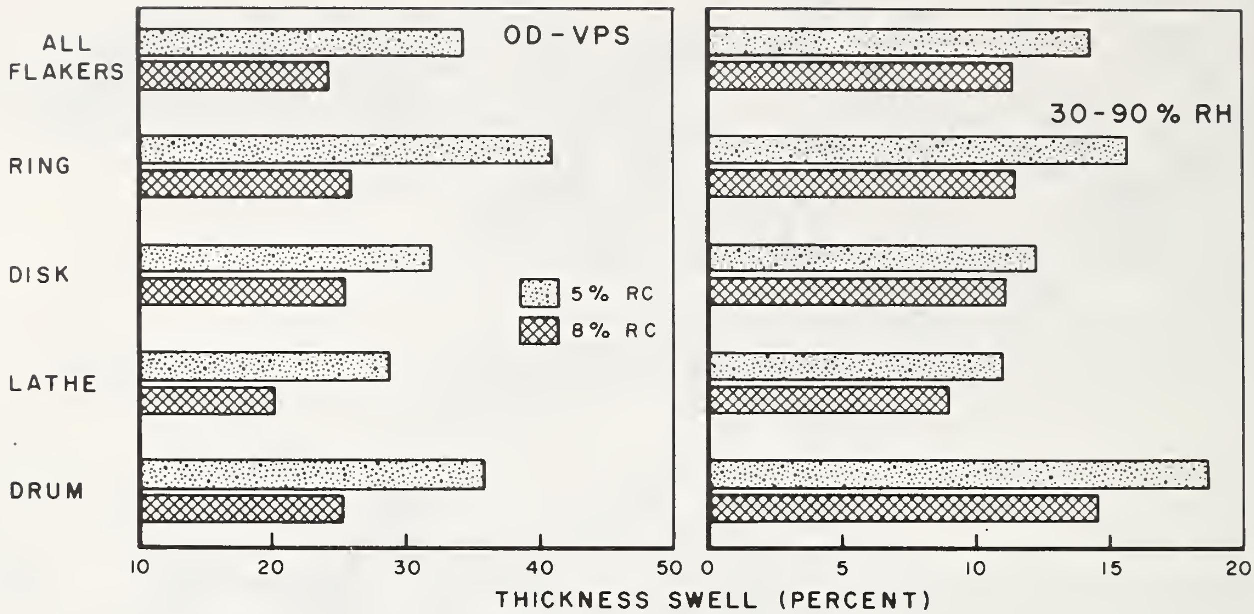


Figure 19. Resin content effect on the average percent thickness swell of red oak and hickory panels combined. Panels were fabricated at a target density of 52.6 pcf with flakes generated from four flakers.

CONSTRUCTION VARIABLES CONSIDERED IN FABRICATION OF A STRUCTURAL FLAKEBOARD

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Abstract

Flake geometry, flake quality, flake alignment, average density, density gradients, layer thicknesses, and resin content were factors considered in determining the final construction details on structural flakeboards made from (1) western softwoods and (2) southern hardwood residues. After making compromises between board properties, a three-layer design was recommended for both board types. Long, thin face flakes enhanced bending properties while thick core flakes maximized internal bond strengths.

The lower compaction ratio associated with high-density hardwood species restricted the range of the variables used, as compared to those considered by the softwood board. The use of high-quality surface flakes and a surface water spray were other methods used to improve the performance of the hardwood board. Alignment of face flakes substantially increased the bending properties in the aligned direction for both board types. Being bound on one hand by economics and on the other by strength and durability requirements, a liquid phenolic resin content of 5 to 6 percent was used for the binder. By carefully choosing construction variables and fabrication techniques, acceptable panels from forest and mill residues were recommended for structural application.

Introduction

The direction of research aimed at utilization of residues in structural boards is determined to a large extent by the form of the residue and the species involved.

The Southern Experiment Station, Alexandria, La., in attempting to economically utilize the smaller hardwood logs, has elected to derive the furnish for a structural board from flakes created on a shaping lathe headrig. A three-layer construction has been developed using long, thin flakes for the faces and thicker, narrower flakes in the core.

The Forest Products Laboratory on the other hand has been charged with making boards from softwood residue ranging in size from 4-foot-diameter logs to small branches (19). The softwood flakeboard is also of three-layer construction. Quality flakes cut from the larger residue, on a disk-type flaker, are used for the face material. Smaller residues, after being chipped, are passed through a ring-type flaker to provide the furnish for the core of the board.

Many factors influence the properties of flakeboard. Construction variables such as board density, press closing speed, and mat moisture content will interact with each other, sometimes in a non-linear fashion, simultaneously to cause favorable and unfavorable reactions in different board properties. Furthermore, mechanical and economical factors such as machinability, resin content, and press time must be considered. Consequently, the choice of variables used (in constructing a flakeboard with structural characteristics) must be a compromise. Because of species effects, a wider range of variables is usually tolerable when using softwoods, than when using the high-density hardwoods.

Review of Major Variables

Flake Geometry

To meet the Forest Service performance goals of 800,000 psi average modulus of elasticity (MOE) and 4,500 psi near-minimum modulus of rupture (MOR) at reasonable board density levels, special attention was given to flake geometry. Numerous researchers have shown bending properties to increase directly with flake length and inversely with flake thickness (1)(7)(9)(13)(24)(34). Improved bending performance has been shown for flake lengths up to 3 inches (28) and thicknesses as low as 0.006 inch (24).

Slenderness ratio (the relation of flake length divided by flake thickness) is a convenient way of combining these two variables. Slenderness ratios up to 300:1 have been shown to affect favorably bending properties (1)(25)(27) (Fig. 1). Below 1/2 inch, flake width is of minor importance in developing bending properties (4).

There appear to be limits at which the effects and interactions of all of these flake geometry variables cease to be important (4)(9)(16)(34). A practical range from the standpoint of flake production, handling, and mat formation lies between 2 and 3 inches in length, 0.015 to 0.05 inch in thickness, and between 1/2 to 1 inch in width. In contrast to bending properties, internal bond strength (tension perpendicular to the surface)

increases as the flake thickness increases and flake width decreases (1)(12)(18). Depending on particle configuration and relative size, decreasing flake length also increases internal bond (IB)(1). While the true significance of the IB property is not fully understood, it can be correlated to interlaminar shear (23) and is often used as an indicator of bonding quality and durability (the ability of a board to withstand accelerated aging).

Flake geometry affects durability by its influence on springback. Springback is the irreversible thickness swelling which occurs after wetting and is attributed to the release of stresses accompanied by some loss of glue bonds. As mentioned previously, increasing flake thickness improves strength properties perpendicular to the surface. Decreasing flake thickness, however, improves thickness swelling and linear expansion properties (1)(18)(24). Springback generally increases with an increase in flake thickness (18)(25). The optimum flake thickness for durability and dimensional stability then becomes a compromise. Since the range of flake thickness in which significant improvements occur differs with each property and also depends to some extent on other flake dimensions, the optimum geometry is best found by empirical methods.

The effect of flake length on either durability or dimensional stability can also vary. Lehmann (18) found no connection between flake length and thickness swelling but did show reduced linear expansion in boards made from long flakes. Post (25) found springback increased with increasing flake length up to 2 inches but was drastically reduced with a 4-inch-long flake.

Other board properties such as edgewise shear and nail holdings also depend to some degree on flake geometry. However, no problem was encountered in meeting the goals and no effort was made to alter these properties by further manipulating the variables.

Flake Quality

The importance of flake quality in promoting resin efficiency and bond formation is shown in studies by Lehmann (18). Although quality is hard to define, the term is generally used to describe a furnish having flakes with smooth-cut surfaces and edges and possessing a minimum of fines.

The term is relative, of course, as shown by Price's (26) comparison of a veneer flake and a flake cut on a shaping headrig. While both types are considered to be quality flakes, the veneer flake has a decided advantage as indicated by IB tests. Quality can be enhanced by such practices as presoaking the logs in hot water. Heebink (8)(10) and Maier (21) agree that a long chip (1-1/2 to 2-1/2 inches) will produce a better furnish when flaked in a ring flaker than the conventional 3/4-inch pulp chip. This is because the long chips align themselves with the grain parallel to the knives. Longer flakes with less cross grain and fines are produced.

While flake quality does affect internal bond directly (26), there seem to be strong interactions between quality, flake geometry, and bonding. Part of this interaction is due to resin efficiency (12)(17), part due to differences in orientation of the particles with respect to the board thickness direction or orientation of the grain within the particles, and part attributed to conditions present in the core during bond formation.

Flake Alignment

The tremendous influence of flake alignment on increased board bending properties are investigated as early as 1952 by Klauditz (15). Other researchers have shown the extent of improvement with various flake types and degree of alignment (2)(4)(26)(31). Using random orientation of ring-cut Douglas-fir for the core and aligned disk-cut face flakes at a face:core:face ratio of 15:70:15 percent, Ramaker and Lehmann (28) increased bending stiffness in the aligned direction by 73 percent and strength by 36 percent over a similar board with randomly distributed face and core flakes. The change of properties in one direction is, of course, made at the expense of those same properties in the opposite (90°) direction, (Fig. 2). Flake alignment does affect the dimensional stability of the board but has no effect on internal bond. Few data are available to show the effect of flake alignment on the various shear strengths (5).

Density

Increasing board density improves all the physical strength and stiffness properties. Comparison of density versus MOE for various species is well illustrated by Heebink (11) and Hse (12)(13). Vital (35) has shown that the relationship between compaction ratio (board density divided by species density) and bending properties is independent of species mix. Internal bond is very sensitive to density (12)(18)(22). Nail-holding properties and hardness likewise depend to a great extent on board density. Research relating density to either thickness swelling or linear expansion is rather inconsistent. There appears to be some rather important interactions occurring between density, particle geometry, and bonding conditions which often tend to mask or even change the

effect of density. Density has been shown to affect the rate of change in thickness swelling by controlling the rate of water absorption (29).

An important board characteristic stressed by Kelly (14) is the density gradient which exists throughout the thickness of hot-pressed boards. The gradient is controlled by a number of factors including press temperature, press closing time, mat moisture content, and flake layer thickness (3)(32)(33), (Fig. 3). Internal bond failures generally occur in the center line of hot-pressed boards because this is the low-density region associated with the vertical density gradient. Any controlled shifting of the density gradient to favor bending characteristics developed in the face layer necessarily decreases the core density and consequently tends to lower IB.

Layering

Since many of the boards' physical properties depend on the characteristics of a restricted area of the thickness zone, it is advantageous to form a layered board. By manipulating the variables independently in the various zones, board properties can be enhanced more economically. Geimer, et al. (3) have indicated that a face:core:face ratio of 15:70:15 will account for 52 to 62 percent of the stiffness increase possible if the boards were made of all-face material. The thin face layers also allow for a greater utilization of poor grade, smaller size residue in the core, and permit flake alignment in the faces independent from the core. Use of a three-layer construction technique also permits utilizing different resin levels or resin types in face and core.

Resin Content

All boards made in the Forest Service Structural Flakeboard From Forest Residues Program used a phenol-formaldehyde resin to achieve exterior durability performance. Increasing resin content does improve all of the physical properties (18)(20)(24). The rate of improvement, however, varies with different properties and optimum levels are affected by particle geometry. MOE and MOR increase only slightly if at all above 5 percent resin content (17)(24)(30). IB levels continue to increase at resin levels of 8 percent. Durability is increased when the resin content is raised from 3 to 9 percent (18)(6). Thickness swelling as measured in relative humidity conditions show various responses to resin content levels dependent on the test conditions and the particle geometry. There appears to be an optimum level around 12 percent above which thickness swelling again increases (30). Particle geometry not only affects resin efficiency but also controls curing rate. Use of thick, coarse, but small particles in the core material results in a more porous core layer and provides for better steam release during the pressing cycle, which in turn aids the resin curing process. The same high-porosity conditions exist in low-density boards and partially explains why internal bond and density are often not well correlated.

Optimization of Variables

The effects of resin content, density, flake thickness, and flake length on bending stiffness (MOE) of homogeneous Douglas-fir flakeboard are shown in Figure 4. With 6 percent resin content, MOE varied from a low of 402,000 psi (0.045-inch-thick, 1/2-inch-long flake and 37.5 pounds-per-cubic-foot-density board) to a high of 665,000 psi (0.030-inch-thick, 2-inch-long flake and 42.5 pounds-per-cubic-foot board). Decreasing the flake thickness to 0.020 inch and increasing length to 3 inches further increased the level of MOE attainable in a homogeneous board to 800,000 psi (Fig. 5). The relative MOE level attainable with 3-inch hardwood flakes is also shown in Figure 5 and partially reflects the differences between the softwood and hardwood slenderness ratio curves shown in Figure 1. It is readily apparent that to meet the bending stiffness goals a very high slenderness ratio or high board density must be used with the hardwoods. Work done at the Southern Station indicates that a compaction ratio of 1.185 is needed if the bending properties are to be met with a 0.015- by 3-inch flake (Fig. 6). Using a specific gravity of 0.639 for an average furnish species, a board density of 47.5 pounds per cubic foot is necessary to attain the 800,000 psi MOE value.

Trial experiments with a three-layer, 41-pounds-per-cubic-foot Douglas-fir flakeboard showed that an effective MOE of 760,000 could be obtained by using a 0.020- by 2-inch disk flake in the faces and 0.050- by 2-inch ring flakes for the core. By using a 0.020-inch-thick core flake and a 3-inch-long face flake, MOE increased to 865,000 psi (Fig. 7).

The possibility of using flake alignment to obtain rather large increases in bending properties was also investigated. Board stiffnesses were increased by 70 to 75 percent in the aligned direction using Douglas-fir furnish (Fig. 8). Aligned hardwood boards showed slightly smaller bending stiffness increases, 44 to 57 percent, but were still dramatically stiffer than a random configuration. The effect of flake alignment on MOR properties was similar to that shown for MOE (13)(28).

Numerical differences in bending properties of the three-layer boards

(Fig. 7) as compared to those homogeneous boards (Fig. 5) may be explained in part by a difference in density gradients. The rates of heat and moisture transfer during pressing and the resultant plastization of the furnish can be affected by the various layer combinations of face and core material (Fig. 9). Twelve percent mat moisture was used in constructing the three-layer boards, as compared to 10 percent mat moisture used in the homogeneous construction. Increased moisture will tend to increase the density gradient. The skin or I-beam effect is extremely important in achieving bending properties as shown by the rapid increase in MOE (tensile) experienced in face layer material at specific gravities exceeding 0.75 (Fig. 10). A water spray as used in constructing the hardwood structural boards will further promote a sharp density gradient approaching that shown for the fast press closure in Figure 3.

The effects of density, flake thickness, flake length, and resin contents on the internal bond property is shown in Figure 11. The relative magnitudes of the internal bond increase (Fig. 11) as opposed to the bending properties decrease (Fig. 7) with an increase in flake thickness was a major factor in using a thicker core flake. Additional internal bond increases were achieved with the hardwood lathe flakes by reducing the average flake width in a milling process. Data showed that an IB of 70 could be attained in the hardwood board at a comparison ratio of 1.15 (Fig. 6). With the five species mix under consideration this ratio corresponds to a density of 46.0 pounds per cubic foot.

The relative degree to which the different construction variables control dimensional stability is shown in Figures 12 and 13. Flake length has little effect on thickness swelling but does markedly control linear expansion. Reducing flake thickness decreases both TS and LE. Increasing density causes only a slight increase in either TS or LE, while increasing resin content from 3 to 9 percent affects a significant reduction in TS but reduces LE only slightly. The pattern of springback response to the variables is similar to that of thickness swelling (Fig. 14).

Retention of bending and IB properties following accelerated aging are shown in Figure 15 for a three-layer Douglas-fir board made using two densities and two resin content levels. The retention levels of MOE and MOR are based on measurements in the board's expanded condition but calculated on the initial thickness. This analytical procedure describes the board's retention of initial load-carrying capacity rather than change in the material. The internal bond data on the other hand are directly related to density and consequently reflects the influence of springback. Whereas resin content has little to do with retention of the bending properties as calculated, lowering resin levels from 7 to 5 percent considerably reduces IB retention.

Final choice of the variables used to manufacture large, 1/2-inch-thick panels is given in Table 1. Analysis of the above referenced data can aid in further manipulation of the variables to achieve board property levels desired for specific structural applications.

Summary

In an attempt to maximize those board properties generally accepted as critical for structural purposes, compromises were made in arriving at optimum construction variables. The compaction ratio (board density:species density) effect had considerable influence in determining the parameters used for hardwoods as opposed to those developed for the softwood species. Average density levels of 40 to 42 pounds per cubic foot appeared as optimum in Douglas-fir laboratory panels while panel density was increased to 47.5 pounds per cubic foot for the hardwood boards. Economics and durability were the major criteria for establishing the resin level at 5 to 6 percent.

Face flake geometry and quality are largely responsible for attaining bending properties. A slenderness ratio (flake length:flake thickness) of 100 was used with the Douglas-fir boards while a ratio of 200 was used with the hardwood boards. Steep vertical density gradients, favorable to bending properties, were achieved in both boards by using a fairly rapid press closing of (3/4-1 min.) A surface water spray further increased the density gradient in the hardwood panels.

Use of long but thick and narrower flakes in the core promoted internal bond properties with a minimum reduction in bending characteristics. Dimensional stability and bending durability characteristics were adequately obtained with the selected variables. Retention of internal bond strengths following aging were marginal but could be improved with additional resin. No problem was encountered in meeting goal specification for nail pull-through, nail withdrawal, or the various tension, compression, and shear properties; as such, they were not considered directly in optimizing the variables. Studies were extended to establish the practical limit of strength and other property improvements attainable with further manipulation of the variables. Flake alignment proved to be a method of achieving high bending properties (well

over a million psi) in the critical aligned direction.

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Table 1.--Variables chosen to manufacture 1/2 inch by 4- by 8-foot structural flakeboard panels from forest residues.

Manufacturing Variables	Softwood	Hardwood
Raw material	Douglas-fir residues	Equal amounts of white oak, hickory, southern red oak, sweetgum, and southern pine
Panel density	43 pcf[1]	47.5 pcf[2] random, 45.5 pcf[2] alined
Face flakes	0.02 x 1 x 2 inch disk flakes	0.015 x 3 inch x random width, shaping headrig flakes, bolts heated to 160°F
Core flakes	0.05 x 2 inch x random width ring flakes	0.025 x 3 inch shaping headrig flakes, milled to reduce width
Face:core:face flake ratio	15:70:15 by weight	25:50:25 by weight
Phenolic resin	5 percent solids[3]	6 percent solids[3]
Wax emulsion	1 percent solids[3]	1 percent solids[3]
Mat moisture content	10 percent	10 percent, additional 4.32 g of water sq/ft sprayed on surface
Press cycle	10 minutes at 350°F Press close to stops in 1 minute	5 minutes at 350°F Press closed to stops in 3/4 minute

[1] Based on oven dry weight and nominal volume.

[2] Based on 6 percent panel moisture content.

[3] Based on oven dry weight of flakes.

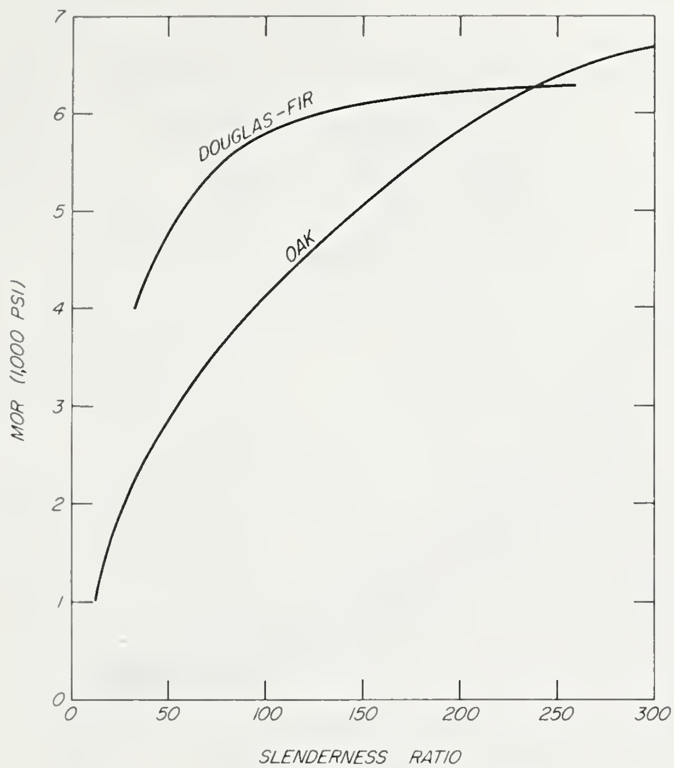

Figure 1. - Slenderness ratio (flake length/flake thickness) vs. modulus of rupture (MOR). Douglas-fir values are from Brumbaugh (1); oak figures from Post (24).

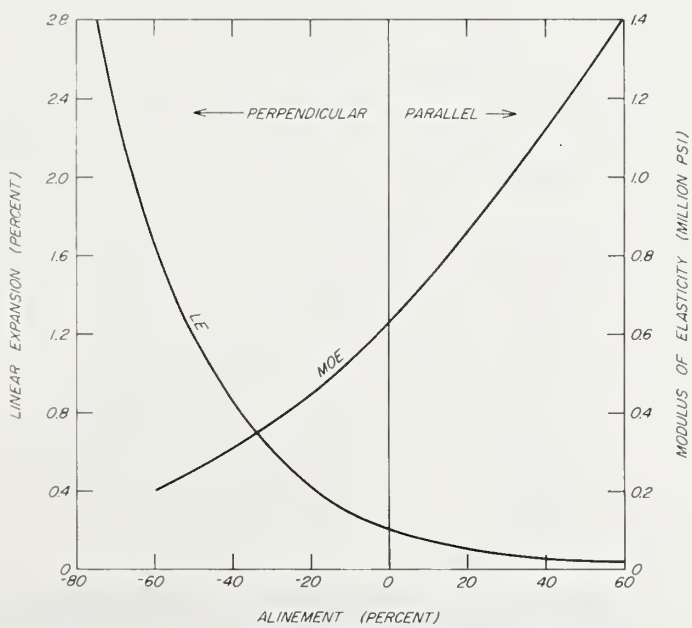

Figure 2. - Percent of flake alignment vs. linear expansion (LE) and modulus of elasticity (MOE). From Geimer (4).

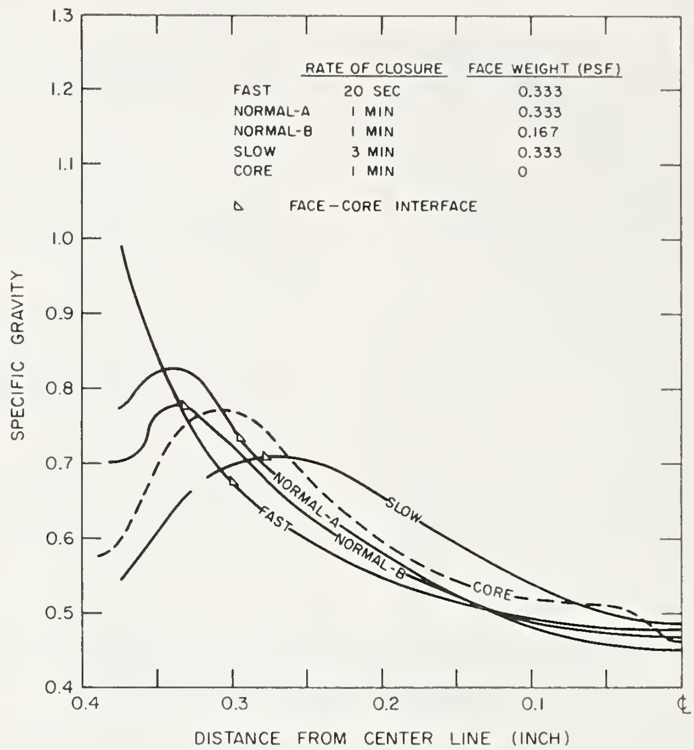

Figure 3. - Density gradient for 3/4-inch particleboards as affected by rate of closure and face weight. From Geimer, et al. (3).

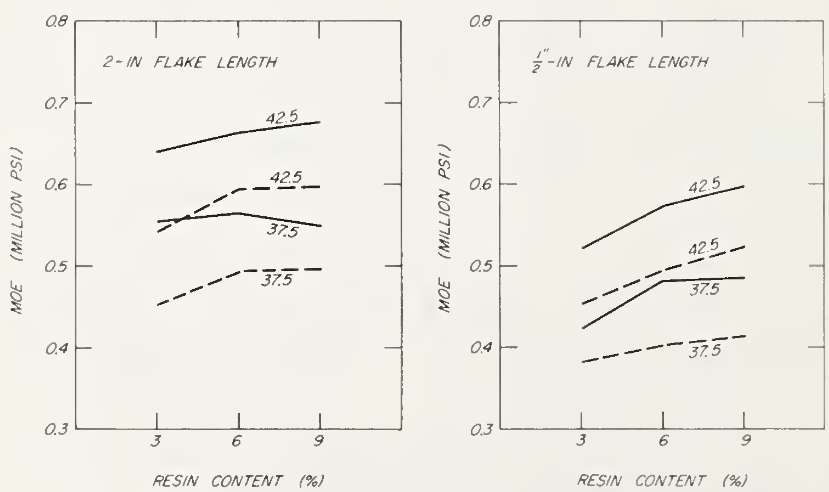

Figure 4. - Effect of resin content, density, flake thickness, and flake length on MOE. Values from Lehmann (18) with data adjusted to densities of 37.5 or 42.5 pcf.

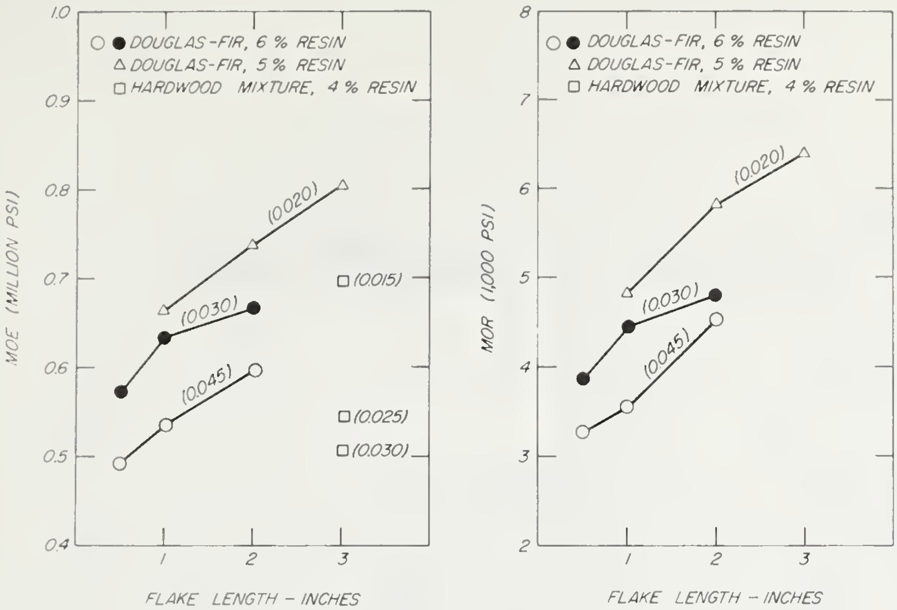

Figure 5.- Effect of flake length and flake thickness on modulus of elasticity (MOE) and modulus of rupture (MOR). Number in parenthesis is flake thickness in inches. Values for Douglas-fir 6% resin solids are from Lehmann(18); Douglas-fir 5% resin solids from Geimer(4); hardwood mixture 4% resin solids from McMillan and Koch(22).

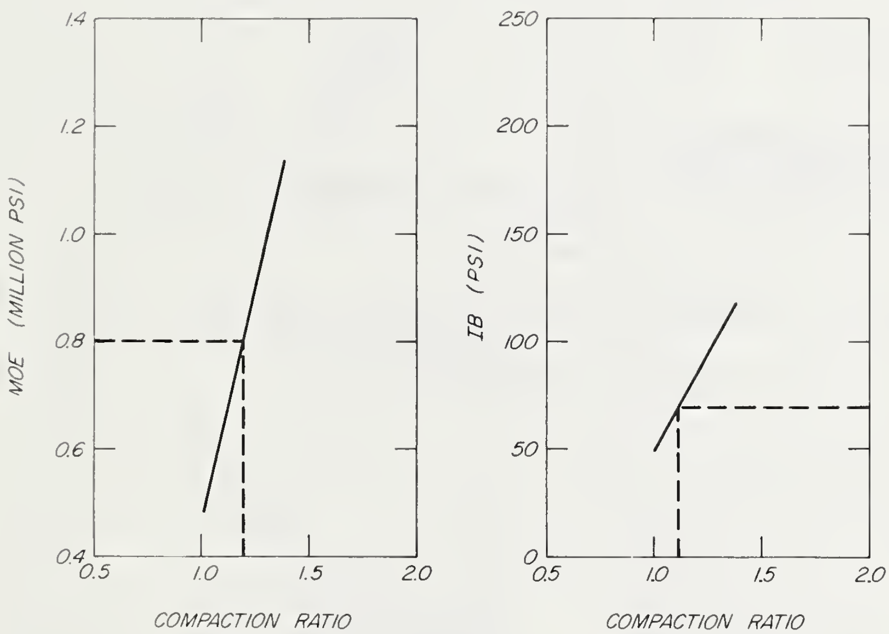

Figure 6.- Minimum compaction ratio required to achieve the FS goal of 800,000 psi MOE and 70 psi IB using the hardwood mix. Dotted line shows ratio of 1.18 for MOE and 1.15 for IB. Lathe flakes are from an equal mixture of four hardwoods and southern pine, from Hse(13).

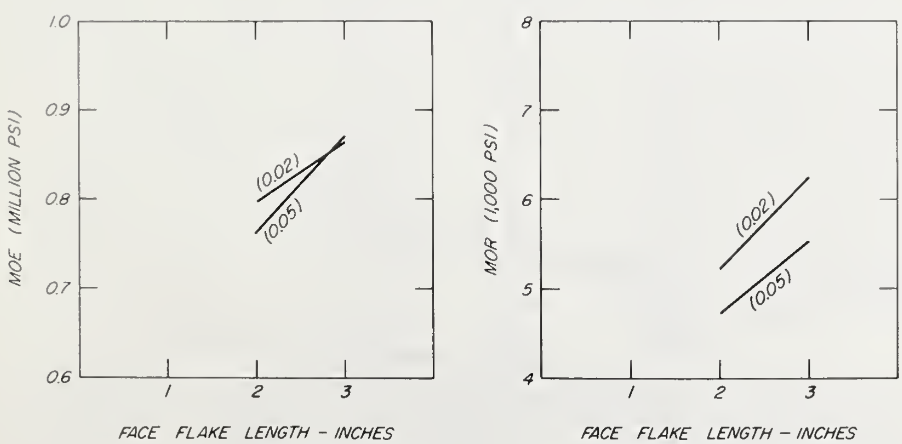

Figure 7.- Effect of core flake thickness and face flake length on MOE and MOR of three-layer structural flakeboard. Numbers in parentheses are core flake thicknesses in inches. Values are from Ramaker(28).
12% face MC, 8% core MC
15-70-15%, face:core:face ratio
5% PF resin
Ave. panel density 41.0 pounds per cubic foot

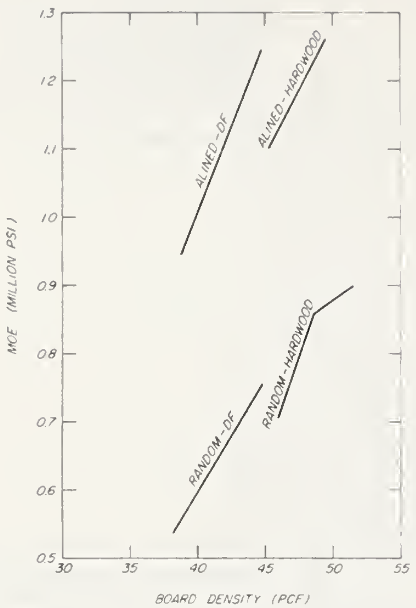

Figure 8.- Effect of density and alignment on MOE of three-layer boards. Values for Douglas-fir (5% resin solids) are from Ramaker (28); values for hardwood mix (5.5% resin solids) are from Hse(13).

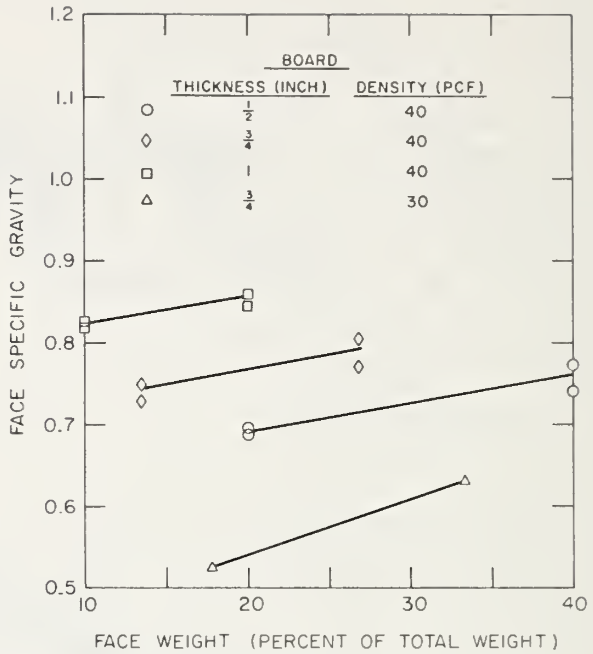

Figure 9.- Face layer specific gravity as affected by face weight and total board thickness.

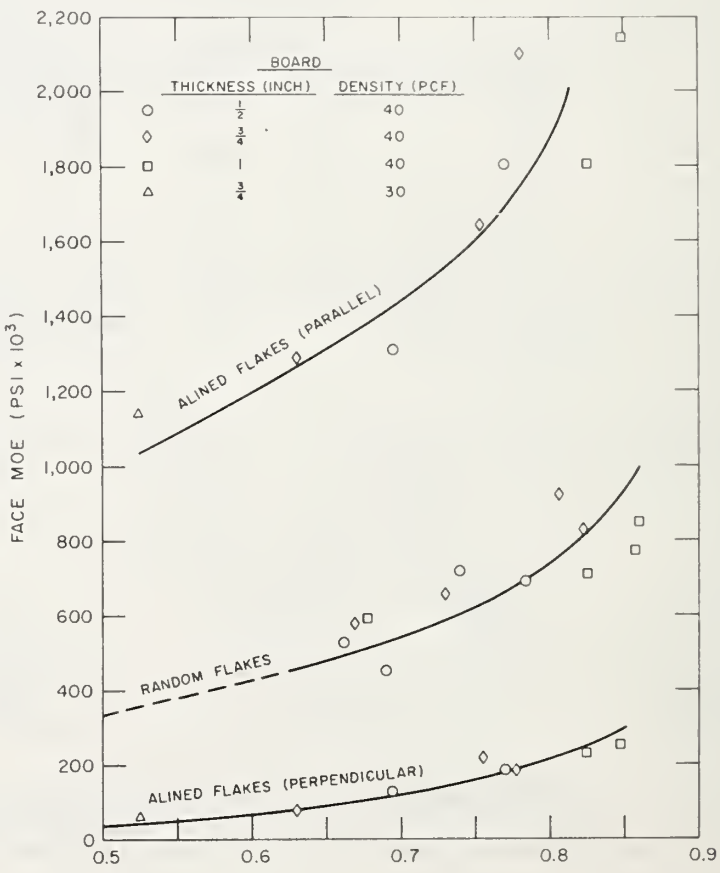

Figure 10.- Influence of specific gravity on the MOE (tensile) and total board thickness.

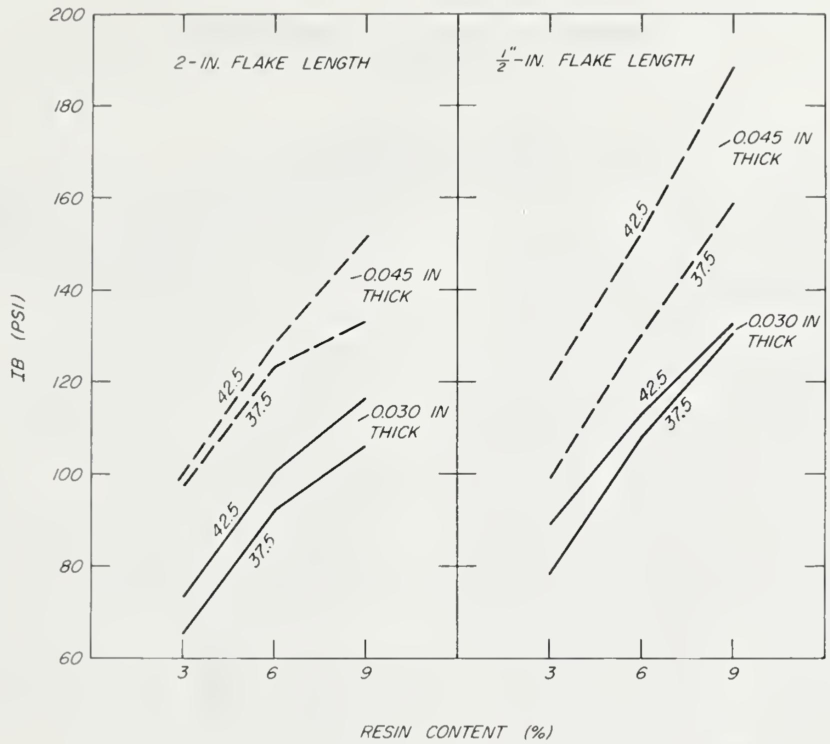

Figure 11. - Effect on internal bond of resin content and density, two flake thicknesses, and two flake lengths. Values are from Lehmann (18).

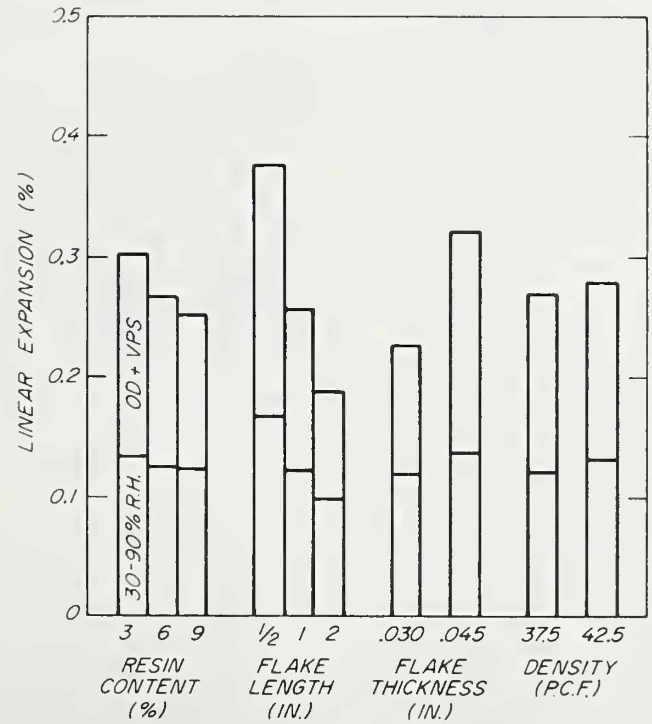

Figure 12. - Overall effects of variables on linear expansion of Douglas-fir flakeboards in 30 to 90 percent relative humidity and ovendry and vacuum-pressure-soak tests. Values are averaged across the other variables. From Lehmann (18).

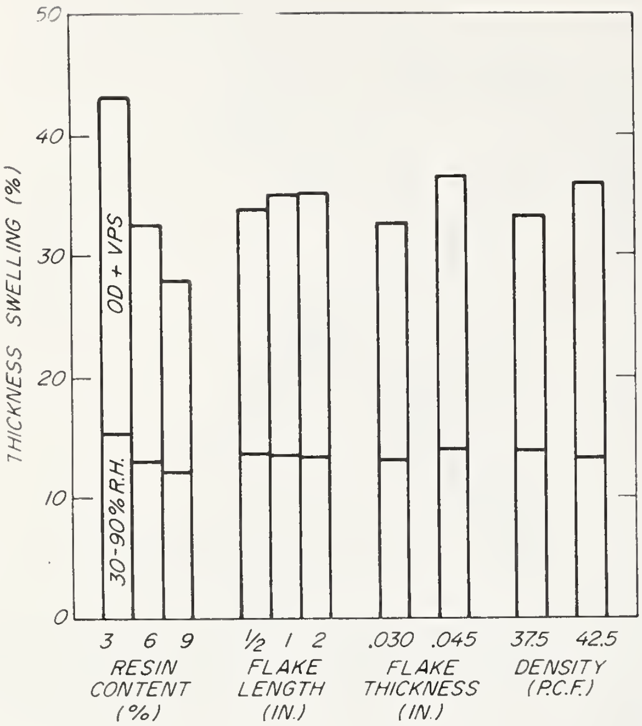

Figure 13. Overall effects of variables on thickness swelling of flakeboards in 30 to 90 percent relative humidity and ovendry and vacuum-pressure-soak tests. Values are averaged across the other variables. From Lehmann (18).

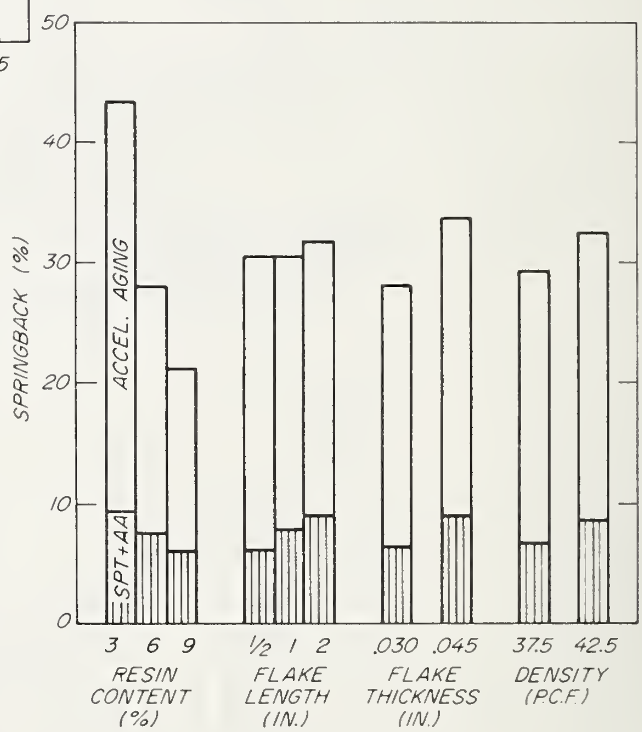

Figure 14. Overall effects of study variables on thickness swelling retention of flakeboards after steam post-treatment and/or accelerated aging exposure. Values are averaged across the other variables. From Lehmann (18).

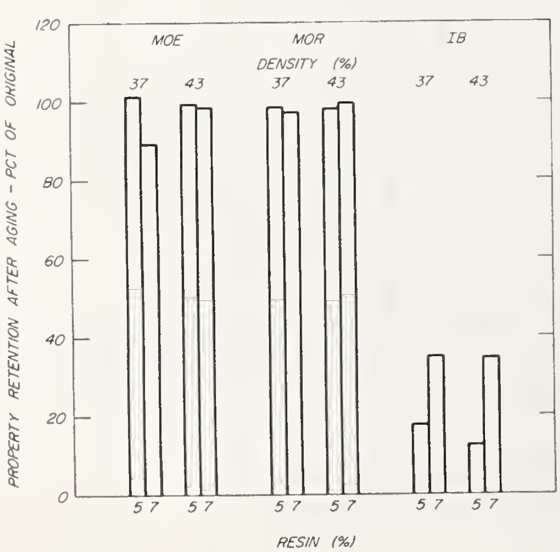

Figure 15. Retention of properties following accelerated aging (ASTM D1037). Values are from Ramaker (28).

DEVELOPMENT OF A RESIN SYSTEM FOR GLUING SOUTHERN HARDWOOD FLAKEBOARDS

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Abstract

A series of experiments was conducted to develop an effective economical resin system for gluing flakeboard of mixed southern hardwoods. First, a phenolic resin was formulated with a second formaldehyde addition at reaction concentration of 47.5% and reaction temperature of 95°C. Such resin yielded satisfactory bonds in laboratory boards made of mixed hardwoods with (1) a minimum resin content of 4%, (2) a minimum hot press time of 4 minutes, (3) a maximum mat moisture content of 14%, and (4) a hot press temperature of 325°F. The effects of board and wood density on bonding strength may best be expressed by flake compaction in the panel. Board strength increases in proportion to compaction ratio (i.e., the ratio between board density and wood density). Because high-density flakes require higher panel density than low density flakes to attain an adequate compaction ratio, boards of high-density species tend to be excessively heavy.

To produce a flakeboard of acceptably low density from wood of many species and densities, a phenolic alloy of phenol-formaldehyde resin and polyisocyanate was developed. The key to this alloying process is first applying minor amounts of polyisocyanate before application of major amounts of phenolic resin on wood furnish, and then reacting the combined adhesive in situ to obtain an improved thermosetting adhesive resin suitable for hardwood flakeboard. The performance of the new phenolic alloy is superior to that of phenolic resin under high flake moisture content, low resin content, and low panel density.

Introduction

This paper is one of a series describing efforts of the Pineville, Louisiana, Laboratory of the Southern Forest Experiment Station to develop an effective economical resin system for gluing hardwood flakeboard of mixed southern species. The study is a sequence of three experiments: (1) formulation of an economical fast-cure phenolic resin for exterior hardwood flakeboard; (2) gluing properties of flakeboards from hardwoods growing on southern pine sites; and (3) development of a new adhesive system to improve glue bond of hardwood flakeboard.

Experiment 1. Formulation of an Economical Fast-cure Phenolic Resin

Phenolic resins are excellent adhesives for exterior plywood and can readily be used to make exterior flakeboard resin. Optimum viscosity of a flakeboard resin, however, is considerably lower than that of the conventional plywood resin. Consequently the resin for flakeboard requires a longer press time to cure completely than plywood resin (i.e., 8 to 10 minutes for flakeboard resin, 3 to 5 minutes for plywood resin). To reduce press time, a phenolic resin must have maximum chemical reactivity.

A. Optimizing Reaction Concentration

Bond quality of plywood specimens made with different resins revealed that the following formulation variables for phenolic resins are best (1):

Formaldehyde to phenol molar ratio of 1.8 to 1.9
Sodium hydroxide to phenol molar ratio of 0.4 to 0.5
Reaction concentration, an undetermined number greater than 43%.

Although results from plywood specimens are not strictly applicable to flakeboard resins, they provide a starting point for further refining of formulation variables. Therefore, the first experiment evaluated reaction concentrations in detail.

Resin Preparation

Phenol-formaldehyde resins were prepared in the laboratory at one of three reaction concentrations: 43.0%, 47.5%, or 52.0% by weight. Molar ratio of sodium hydroxide to phenol was fixed at 0.45, and molar ratio of formaldehyde to phenol was 1.85. Each resin was replicated three times. To prepare each resin, all of the phenol, formaldehyde, and water were placed in the reaction kettle. The sodium hydroxide was added as a catalyst at 20 ml every 10 minutes to increase the pH gradually from 8.5 to 10.5. To initiate the reaction, the mixture was quickly heated and maintained at 96-100°C (reflux temperature). When viscosity reached Gardner-Holt viscosity C ($\approx$ 90 centipose), temperature was reduced to 70°C. When viscosity reached Gardner-Holt viscosity H($\approx$300 centipose), the reaction was stopped by rapidly cooling the mixture to 25°C.

Panel Preparation

All panels were prepared in the laboratory with flakes 3 in. long, 3/8 in. wide, and 0.015 in. thick. The flakes were from rotary-peeled veneer cut on a metal-working lathe and then clipped to width. Mixed hardwood flakes--50% red oak (*Quercus falcata* Michx.), 25% hickory (*Carya* sp.), and 25% sweetgum (*Liquidambar styraciflua* L.)--were dried to an average moisture content of 2% to 3% before adhesive was added. General conditions for panel preparation were:

- Panel size--1/2 by 14 by 14 in.
- Panel density--43.5 lbs per cu ft (0.696 specific gravity)
- Resin content--resin solids equaled 5% of the ovendry weight of the wood furnish
- Hot press temperature--335°F
- Press closing time--45 seconds
- Hot press time--4.5 or 7.5 minutes

Sampling and Testing

All boards were conditioned in a chamber controlled at 50% relative humidity and 80°F until their moisture contents averaged 5.9%. After conditioning, each board was cut into 2- by 2-in. specimens for testing internal bond. Ten specimens were selected at random from each board. Internal bond tests were performed in accordance with ASTM standards for evaluating the properties of wood-base fiber and particle panel materials (D 1037-64).

Results and Discussion

As expected, internal bond (IB) was consistently higher with resins cured 7.5 minutes than with those cured 4.5 minutes (Figure 1). With the shorter press time, the resin formulated at 47.5% concentration yielded the best IB; with the press time of 7.5 minutes, however, the resin formulated with 52% concentration gave the highest bond strength. Apparently the 52% resin requires slightly longer cure time to develop optimum strength than the 47.5% resin. Since fast cure time, not bond strength, was the primary objective of the study, the 47.5% reaction concentration was used for subsequent experiments.

B. Effects of Catalyst, Second Formaldehyde Addition, and Reaction Temperature

Procedure

To increase chemical reactivity more and to decrease cure time, three additional factors in resin formulation were considered: (1) effect of a second formaldehyde addition, (2) preparation of a "high ortho" resin that cured rapidly by means of oxides or hydroxides of a bivalent metal ion such as calcium, and (3) effect of reaction temperature. Thus, the variables in the experiment were:

1. Formaldehyde addition
   a. 1.8 mole at beginning
   b. 1.5 mole at beginning, 0.3 mole after 2.5 hours of reaction time
2. Catalysts
   a. Sodium hydroxide
   b. Calcium hydroxide
3. Reaction Temperatures
   a. 95°C
   b. 75°C for first 2.5 hours, then increased to 95°C

Molar ratio of formaldehyde to phenol was 1.85, reaction concentration was 47.5%, and molar ratio of sodium hydroxide to phenol was 0.45. Each resin was replicated four times.

With both catalysts, reaction pH was adjusted initially to 8.5 and gradually increased to 10.5. However, because of rapid loss of water solubility in the calcium resin, sodium hydroxide was added after a reaction time of 1 hour.

Other details of resin preparation, board manufacture, and testing were as described in Section A. Differences among treatments were evaluated for statistical significance ($P = 0.05$) by analysis of variance.

Results and Discussion

Average IB values were substantially greater for resins cured 7.5 minutes than for those cured 4.5 minutes (Table 1). There were no significant differences in IB among various resins cured 7.5 minutes. With the 4.5-minute cure time, however, timing of formaldehyde addition interacted significantly with reaction temperature to affect bond strength. At high reaction temperature, IB strengths of resins with a second formaldehyde addition averaged significantly higher (80 psi) than strengths of resins with one-step addition of all formaldehyde (69 psi). At low reaction temperatures, however, IB was slightly greater for resins made with the one-step addition of all formaldehyde (70 psi) than with the two-step addition (68 psi).

No significant differences in bond strength between resin catalyzed with monovalent sodium and bivalent calcium ions was detected. Although a calcium hydroxide catalyst reportedly results in formation of "high ortho" thermoplastic phenolic resin with a fast-cure rate (2), the calcium catalyzed thermoset phenolic resin reported here offered no significant improvement on IB as compared with a sodium catalyzed system at the short cure time (4.5 minutes). Explanation of these apparently conflicting results probably lies in differences between thermoplastic and thermoset phenolic resin in reaction pH and molar ratio of formaldehyde to phenol. Moreover, calcium catalyzed resin had shorter storage life than sodium hydroxide catalyzed resin and lost water

Table 1. — IB STRENGTH RELATED TO RESIN FORMULATION VARIABLES

Catalyst	Reaction temperature	Formaldehyde[a] addition	IB
	(°C)		(Psi)
Hot pressed 4.5 minutes			
NaOH	95	All	72.6
		Second	80.6
	75-95	All	67.8
		Second	69.8
$Ca(OH)_2$/NaOH	95	All	65.4
		Second	79.4
	75-95	All	71.4
		Second	66.6
Hot pressed 7.5 minutes			
NaOH	95	All	107.6
		Second	114.4
	75-95	All	100.8
		Second	102.8
$Ca(OH)_2$/NaOH	95	All	94.2
		Second	108.2
	75-95	All	96.8
		Second	94.6

[a]"All" means all formaldehyde was added initially; "second" means 1.5 mole was added at the beginning and another 0.3 mole was added after 2.5 hours.

solubility rapidly, making reaction of this resin difficult to control.

Of all resins catalyzed with sodium hydroxide, those reacted at high temperature with a second formaldehyde addition yielded highest bond strength. A typical reaction schedule for this resin is summarized in Figure 2.

C. Effects of Resin Content, Mat Moisture Content, Hot Press Time, and Hot Press Temperature

The best resin developed in the previous experiments was tested under various gluing conditions to determine its suitability to a wide range of mill operations.

Board manufacture and specimen preparation were as in Section A, except in the special gluing conditions, as will be specified. Resin performance was measured by IB, bending strength, and stiffness of the panel, according to ASTM standards (D 1037-64).

Resin Content

Resin contents evaluated were 2%, 4%, 6%, 8%, and 10% of ovendry weight of wood furnish. All strengthproperties increased substantially as resin content increased from 2% to 8%; as resin content increased from 8% to 10%, modulus of rupture (MOR) and modulus of elasticity (MOE) increased only slightly and IB decreased (Figure 3). The IB decreased mainly because excess moisture, introduced by the additional resin, resulted in less than optimum gluing conditions.

The lowest resin content to yield adequate bond strength was 4%. An average IB of 31 psi at 2% resin content was about half that called for by U.S. Commercial Standard CS 236-66 for 2B1 and 2B2 boards (65 and 60 psi, respectively).

Mat Moisture Content

Mat moisture contents examined in the experiment were 10%, 12%, 14%, and 16%. Moisture content was adjusted by spraying water on the flakes as they tumbled in a rotating laboratory blender. IB and MOR

decreased and MOE increased as mat moisture content increased (Figure 4). This result is to be expected because high mat moisture contents enhance densification of board surfaces and improve MOE. On the other hand, high mat moisture content may lead to excessive resin penetration and and to formation of excessive trapped steam during hot pressing; either condition weakens IB and MOR.

Small pockets of delamination were found in several of the panels manufactured at 16% mat moisture content. Since production panels are considerably larger than the laboratory panels tested--and hence dissipate steam more slowly--it is likely that the safe limit for mat moisture content is near 14%.

Hot Press Temperature

Hot press temperatures examined in the study were 325°, 365°, 405°, and 430°F. The resin seemed to cure best at a hot press temperature of 365°F, which yielded the highest IB; further increases in press temperature decreased IB (Figure 5). Both MOR and MOE increased as hot press temperature increased, with the exception of MOR at 325°F.

Hot Press Time

Hot press times evaluated were 3, 4, 5, 7, and 9 minutes. All properties (IB, MOR, and MOE) improved as press time increased (Figure 6). A hot press time of 3 minutes was less than the minimum needed to yield adequate bond strength of 70 psi.

D. Mill Run

To examine the applicability of the laboratory results to industrial flakeboard production, 1/2 in by 4- by 8-ft hardwood flakeboards were manufactured at a Westvaco flakeboard plant in Tyrone, Pennsylvania.

Methods

In the laboratory, 150 gallons of phenolic resin were cooked in a 15-gallon reactor. The resin was frozen and shipped to the Westvaco plant. Hardwood flakes produced by a Miller-Hofft flaker[1] were provided by Westvaco. More than half the flakes were red maple (Acer rubrum L.); the rest were a mixture of white ash (Fraxinus americana L.), black cherry (Prunus serotina Ehrh.), and aspen (Populus grandidentata Michx.)

The plant was using a resin content of 7% and a press time of 8 minutes. In view of the large amount of fines in the flake furnish, I felt that the experimental resin content should be 5% even though satisfactory panels were produced in the laboratory with 4%. Press time was 4.5 minutes.

In the first press load, six panels out of 20 delaminated. It was then decided to increase press time by 1/2 minute. Forty panels were successfully produced in two separate press loads at 5 minutes press time with resin content of 5.2% (based on calculation from a metering device). Thereafter, a press load of 20 panels was manufactured at each of the following conditions:

Resin content %	Press time (minutes)
5.2	5
5.2	8
6.3	5
6.3	8

All panels were trimmed to 4 by 8 feet and shipped back to the Pineville, Louisiana, laboratory for testing IB. In addition, a supply of the furnish used in making the 4- by 8-foot panels was also shipped to Pineville, where laboratory panels were made under similar conditions for comparison.

Results and Discussion

Average IB (average specific gravity was 0.737) for the mill and laboratory panels was as in Table 2.

Mill panels had 20 to 22% lower IB than laboratory panels. Poor blending (i.e., application of resin to flakes) in the mill was probably the major factor in the decrease of bond strength; the poor blending was readily apparent in the mill panels (Figure 7).

Average IB in the mill panels was 70 psi when press time was 5 minutes and resin content was 5.2%. The data indicated, however, that a slight increase in either resin content or hot press time would yield a satisfactory bond.

Summary and Conclusions

Although a second addition of formaldehyde is not a common practice in manufacturing standard phenolic resin, it improves bonding quality of resin subjected to short cure times. The resin formulated with a second formaldehyde addition at reaction concentration of 47.5% and reaction temperature of 95°C resulted in highest bond strength. Such resin yielded satisfactory bonds in laboratory boards made of high quality flakes of mixed hardwoods with (1) a minimum resin content of 4%, (2) a minimum

[1]Mention of trade names is solely to identify equipment used and does not imply endorsement by the U.S. Department of Agriculture.

Table 2

Resin content (%)	Internal Bond (psi)			
	Hot pressed 5 min		Hot pressed 8 min	
	Lab panel[a]	Mill panel[b]	Lab panel[a]	Mill panel[b]
5.2	87	70	112	88
6.3	107	86	135	105

[a]Each value is the average of 100 specimens (i.e., 20 specimens per 4 by 8 panel and 5 panels per treatment).

[b]Each value is the average of 75 specimens (i.e., 15 specimens per panel and 5 panels per treatment.

hot press time of 4 minutes, (3) a maximum mat moisture content of 14%, and (4) a hot press temperature of 325°F.

Four- by 8-foot mill-run panels had 20 to 22% less internal bond strength than smaller panels made in the laboratory. A slight increase in either cure time or resin content was therefore indicated for satisfactory bond under mill conditions.

Experiment 2. Bonding Properties of Flakeboards from Hardwoods Growing on Southern Pine Sites

The phenolic resin in Experiment 1 is intended for use in structural exterior flakeboard made from mixed hardwoods grown on southern pine sites. Performance of the resin as related to wood species was therefore an important consideration. In experiment 2, nine hardwood species were selected on the basis of their abundance and wide range of properties. Oaks were given special attention, since they comprise nearly half the South's volume of pine-site hardwoods. The variables studied were:

1) Nine hardwood species	Percent of hardwood volume on pine sites
a) Sweetgum (*Liquidambar styraciflua* L.)	13
b) White oak (*Quercus alba* L.)	12
c) Hickory (*Carya* spp.)	9
d) Southern Red Oak (*Quercus falcata* Michx. var *falcata*)	8
e) Post oak (*Quercus stellata* Wangenh.)	7
f) Black tupelo (*Nyssa sylvatica* Marsh.)	6
g) Red maple (*Acer rubrum* L.)	4
h) Sweetbay (*Magnolia virginiana* L.)	1
i) White ash (*Fraxinus americana* L.)	1

2) Board specific gravity (basis of volume and weight at moisture equilibrium with an atmosphere at 80°F and 50 percent RH).

a) 39.5 lb/cubic foot (pcf) - 0.633 grams/cubic centimeter (g/cc)
b) 44.5 pcf -- 0.713 g/cc
c) 49.5 pcf -- 0.793 g/cc

3) Four replications--The fabrication of 39.5 pcf panels was limited to the five low-density species: sweetgum, black tupelo, sweetbay, white ash, and red maple.

Panel fabrication and testing procedures were as in Experiment 1. Flakes were from rotary-cut veneer 0.015-inch thick clipped to 3-inch length and 3/8-inch width.

Average IB ranged from 51 psi for white oak at a board density of 0.702 g/cc to 385 psi for black tupelo at 0.782 (Table 3). Bond strength increased with panel density for all species except sweetbay.

As expected, IB for the four densest species (i.e., hickory and the oaks) was significantly lower than for the other species, even though the resin coverage was greater. At 44.5 pcf all four species yielded panels with IB values less than the target level of 70 psi. When panel density was increased to 49.5 pcf, however, satisfactory bond strength was obtained.

The effects of board and wood density on bonding strength may best be expressed by their relation to compactness in the panel. Because high-density flakes required higher panel density to attain the same compaction as low-density flakes, the ratio between board density and wood density (i.e., the compaction ratio) was computed (Table 3, column 4) and related to bonding strength.

Regression analysis showed that bonding strength increased proportionately with compaction ratio (Figure 8). To

attain the target IB of 70 psi, the corresponding minimum compaction ratio would be 1.012.

The results also indicate that acceptable bond strength of 60-65 psi can be obtained with the resin for all species, but the required panel density may differ substantially among species. This finding is to be expected since hardwoods vary widely in wood density.

Experiment 3. Development of a New Adhesive System

Experiment 2 showed that panels of dense species compacted sufficiently to meet strength requirements were so heavy-in excess of 50 pounds per cubic foot--that transportation would be costly and on-site handling difficult. Thus, a series of studies were conducted to develop a phenolic alloy which would not only yield specification-grade flakeboard over a broad range of wood species and densities at an acceptable panel density, but would also tolerate high flake moisture content and temperature, high temperature and humidity in the working area, low resin application, and conditions conducive to pre-cure.

A. Formation of Phenolic Alloys

The commercially available polymethylene polyphenol isocyanate with functionality of 2.7 and viscosity of 200 to 275 cps at 25°C was chosen to react with phenolic resin in situ to form a combined adhesive system. A series of five flakeboards each were fabricated according to the following adhesive blending processes:

(A-1) Applied polyisocyanate before the phenol-formaldehyde resin adhesive
(A-2) Applied polyisocyanate and phenol-formaldehyde resin adhesive simultaneously
(A-3) Applied phenol-formaldehyde resin adhesive before the polyisocyanate.

Both phenol-formaldehyde resin and polyisocyanate were applied by conventional air-atomizing nozzles in a rotating drum-type blender. The phenol-formaldehyde resin was 75 percent of the total amount of adhesive and the polyisocyanate constituted 25 percent.

All flakes were produced by a shaping-lathe headrig to average 3 inches long, 0.015-inch thick, and were of random width. The mixed hardwood flakes were 40 percent sweetgum (*Liquidambar styraciflua* L.) and 60 percent southern red oak (*Quercus falcata* Michx.).

The panel fabrication and testing were similar to that of Experiment 1. The general conditions for panel preparation were:

Panel density--46 lb/cu. ft.
Panel thickness--1/2-inch
Resin content--4%
Hot press temperature--300°F
Hot press time--4.5 minutes

Average IB was as follows:

Test	Adhesive blending process	Internal bond (psi)
A-1	Polyisocyanate before phenolic	127
A-2	Polyisocyanate and phenolic simultaneously	89
A-3	Phenolic before poly-isocyanate	67

These results indicate that an improved adhesive system can be achieved by applying minor components of polyisocyanate before the major component of phenolic resin on wood furnish and then reacting the combined adhesive in situ to obtain an improved thermosetting adhesive resin suitable for hardwood flakeboard. The polyisocyanate reacts readily with hydroxy groups or water on the surface of or among the wood fibers to form strong adhesion. Subsequently, a cross-linking reaction between isocyanate and phenolic resin occurs to reinforce the properties of phenolic adhesive.

B. Effects of Polyisocyanate/Phenolic Resin Ratio

Evidence of the superior performance of an adhesive system in which polyisocyanate is applied before phenol formaldehyde resin led to a study to determine the best ratio of polyisocyanate to phenol formaldehyde resin. The following test conditions were chosen:

(B-1)	Polyisocyanate/phenolic resin ratio	0/100%
(B-2)	" " "	10/90%
(B-3)	" " "	20/80%
(B-4)	" " "	30/70%
(B-5)	" " "	40/60%
(B-6)	" " "	50/50%
(B-7)	" " "	60/40%

The panel fabrication and testing were as in earlier tests except the hot press time was 5.5 minutes and total resin content was 5 percent.

Average internal bond strengths were as follows:

Test	Polyisocyanate/phenolic resin ratio	Internal bond (psi) 1-A[2]	1-B[3]	1-C[4]
B-1	0/100	72	72	72
B-2	10/90	99	83	75
B-3	20/80	152	97	80
B-4	30/70	192	112	83
B-5	40/60	208	123	92
B-6	50/50	216	131	100
B-7	60/40	173	139	113

The superiority of applying polyisocyanate before phenolic resin is again apparent. Also, increasing the ratio of polyisocyanate to phenolic resin up to 50/50 resulted in increased bond strength.

C. Effects of Flake Moisture Content

To measure the tolerance of applying polyisocyanate before phenolic resin when wood furnish has a high moisture content, the following test conditions were chosen:

Test	Flake moisture content	Polyisocyanate/ phenolic resin ratio
C-1	4	1/100
C-2	4	10/90
C-3	4	30/70
C-4	4	50/50
C-5	11	0/100
C-6	11	10/90
C-7	11	30/70
C-8	11	50/50

The panels were prepared as previously described, again using a hot press time of 5.5 minutes and resin content of 5 percent.

The average internal bond strengths of the panels were as follows:

Test	Flake moisture content	Polyisocyanate/ phenolic resin ratio	IB (psi)
C-1	4%	0/100%	72
C-2	4	10/90	104
C-3	4	30/70	169
C-4	4	50/50	208
C-5	11	0/100	0
C-6	11	10/90	72
C-7	11	30/70	135
C-8	11	50/50	174

Results again clearly demonstrate the efficiency of applying polyisocyanate before phenolic resin. Flakes having 11-percent moisture content were satisfactorily bonded by applying as little as 10 percent of polyisocyanate before the phenolic resin. In the conventional phenolic resin system steam generated from flakes with high moisture content causes panel delamination during hot pressing.

D. Effects of Panel Density

The high wood density of hardwood species such as oaks and hickory makes fabrication of low density panels difficult. To measure the tolerance of the new adhesive system to high-density hardwood species, southern red oak was used in a study including:

Test	Panel density	Polyisocyanate/ phenolic resin ratio
D-1	41 pcf	0/100%
D-2	41	20/80
D-3	45	0/100
D-4	45	20/80
D-5	49	0/100
D-6	49	20/80

D-1, D-3, and D-5 panels were fabricated with conventional phenol-formaldehyde resin adhesive without polyisocyanate; D-2, D-4, and D-6 panels were fabricated by applying polyisocyanate before phenolic resin. Hot press time and total resin content were again 5.5 minutes and 5 percent. The panels were prepared and tested as described previously.

Average internal bond strength was as follows:

Test	Panel density	Polyisocyanate/ phenolic resin ratio	IB (psi)
D-1	41 pcf	0/100%	21
D-2	41	20/80	84
D-3	45	0/100	44
D-4	45	20/80	124
D-5	49	0/100	92
D-6	49	20/80	116

The panels fabricated with initial application of polyisocyanate had consistently higher internal bonds. Satisfactory panels were produced even at 41 pounds per cubic foot, which was not possible with the conventional phenolic

[2] 1-A means application of polyisocyanate before phenolic resin.

[3] 1-B means application of polyisocyanate and phenolic simultaneously.

[4] 1-C means application of phenolic resin before polyisocyanate.

resin.

E. Effects of Resin Content

In the manufacture of flakeboard panels, resin content strongly affects panel performance and manufacturing economics. Resin is the most expensive item in manufacturing cost. To measure the efficiency of the new adhesive system, the following test conditions were chosen:

Test	Resin content	Polyisocyanate/ phenolic resin ratio
E-1	3%	0/100%
E-2	3	20/80
E-3	4	0/100
E-4	4	20/80
E-5	5	0/100
E-6	5	20/80

The E-1, E-3, and E-5 panels were fabricated with conventional phenol-formaldehyde resin adhesive without polyisocyanate; for E-2, E-4, and E-6 panels polyisocyanate was applied before phenolic resin. The hot press time and panel density were 5.5 minutes and 44 pcf. The panels were prepared and tested as described previously.

Average internal bond strengths were as follows:

Test	Resin content	Polyisocyanate/ phenolic resin ratio	IB (psi)
E-1	3%	0/100%	43
E-2	3	20/80	71
E-3	4	0/100	56
E-4	4	20/80	139
E-5	5	0/100	68
E-6	5	20/80	152

The superiority of the resin system containing polyisocyanate is again apparent for all resin content levels in the test.

These tests confirm that applying polyisocyanate before phenolic resin is superior to phenolic resin alone when used at high flake moisture contents and low resin content levels. Satisfactory flakeboards were formed from high-density species such as southern red oak at significantly lower panel density than that attainable with conventional phenolic resin systems.

References

1. Hse, Chung-Yun. 1972. Influence of resin formulation variables on bond quality of southern pine plywood. Forest Prod. J. 22(9):104-108.

2. Bender, H.L. 1954. Hardening speed of phenoplasts. Mod. Plastics. March, pp. 115-116, 118, 200.

Table 3. — BONDING PROPERTIES OF FLAKEBOARD

Species (1)	Actual board density[a] (2)	Wood density (3)	Compaction ratio (4)	Panel moisture content (5)	IB[b] (6)
	--------g/cc------			%	psi
Sweetbay	0.633	0.481	1.3155	5.4	109
	.708		1.4715	7.2	260
	.738		1.5339	6.6	236
Red maple	.648	.538	1.2044	5.9	97
	.755		1.3988	5.0	284
	.788		1.4648	6.0	315
Sweetgum	.638	.547	1.1659	5.5	81
	.723		1.3213	5.8	171
	.793		1.4493	6.1	196
Black tupelo	.625	.518	1.2075	4.9	113
	.721		1.3920	4.8	239
	.783		1.5118	6.0	385
White ash	.633	.646	.9793	5.0	83
	.708		1.0954	5.2	148
	.800		1.2386	6.0	273
Red oak	.705	.667	1.0577	5.0	55
	.788		1.1815	6.6	146
Hickory	.708	.702	1.0079	5.0	65
	.810		1.1539	6.3	107
Post oak	.703	.733	.9584	7.0	58
	.790		1.0779	6.8	119
White oak	.702	.762	.9211	6.9	51
	.795		1.0428	5.8	88

[a]Volume and weight at equilibrium in atmosphere held at 80°F and 50 percent RH. Nominal values for the three board densities were 0.633, 0.713, and 0.793.

[b] Each value is the average of 20 observations.

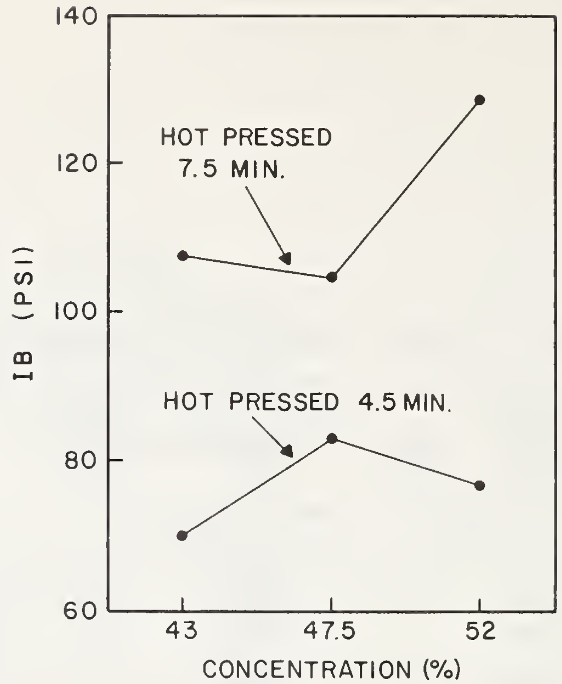

Figure 1. - Relationship of reaction concentration to IB strength of mixed-species boards made from lathe flakes (with Hse's "Fast-cure Phenolic Resin").

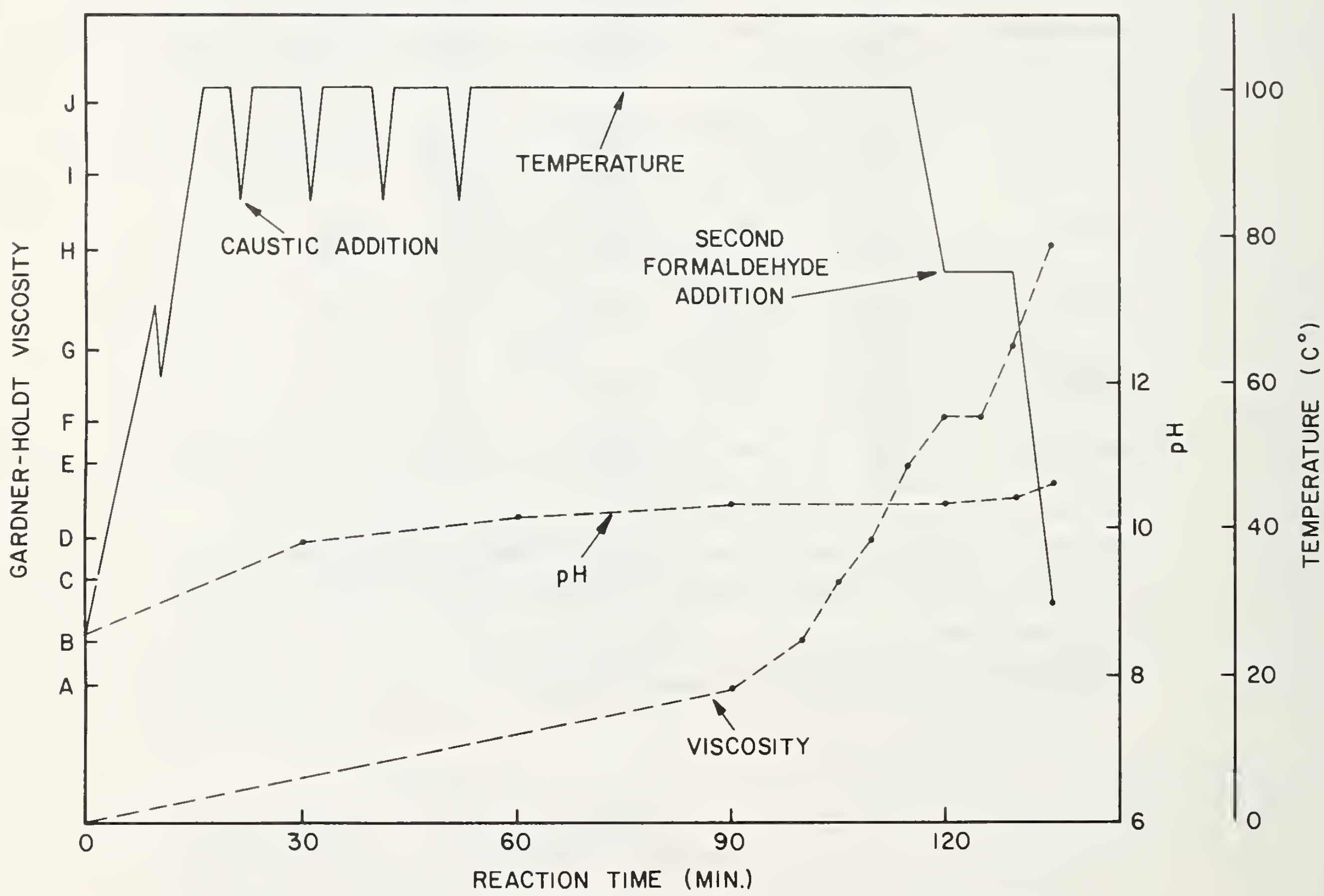

Figure 2. - Viscosity, pH, and reaction temperature as related to reaction time (with Hse's "Fast-Cure Phenolic Resin").

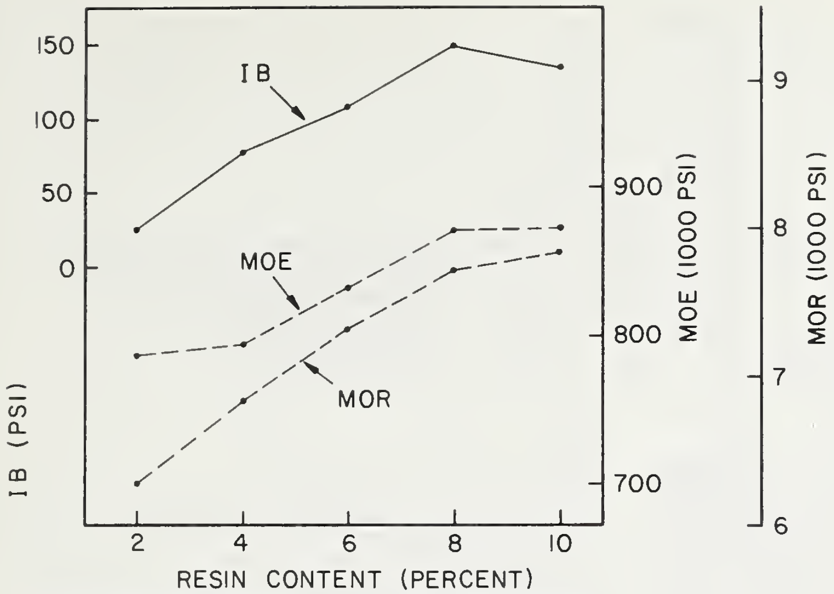

Figure 3. Effect of resin content on IB, MOR, and MOE (with Hse's "Fast-cure Phenolic Resin").

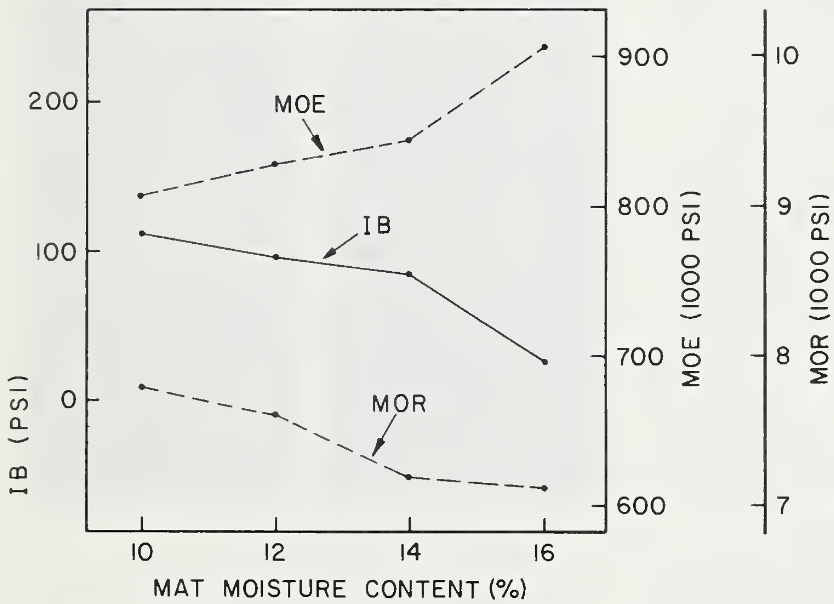

Figure 4. Effect of mat moisture on IB, MOR, and MOE (with Hse's "Fast-Cure Phenolic Resin").

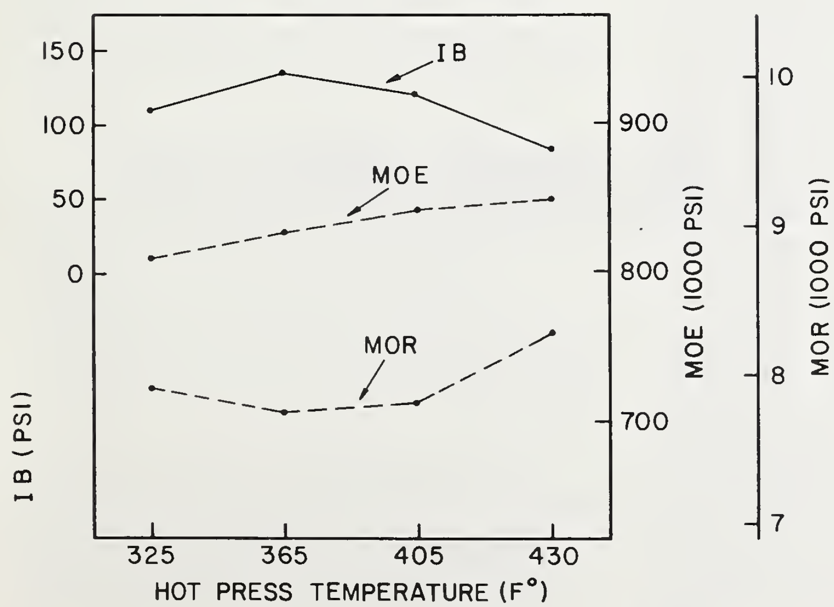

Figure 5. Effect of hot press temperature on IB, MOR, and MOE (with Hse's "Fast-Cure Phenolic Resin").

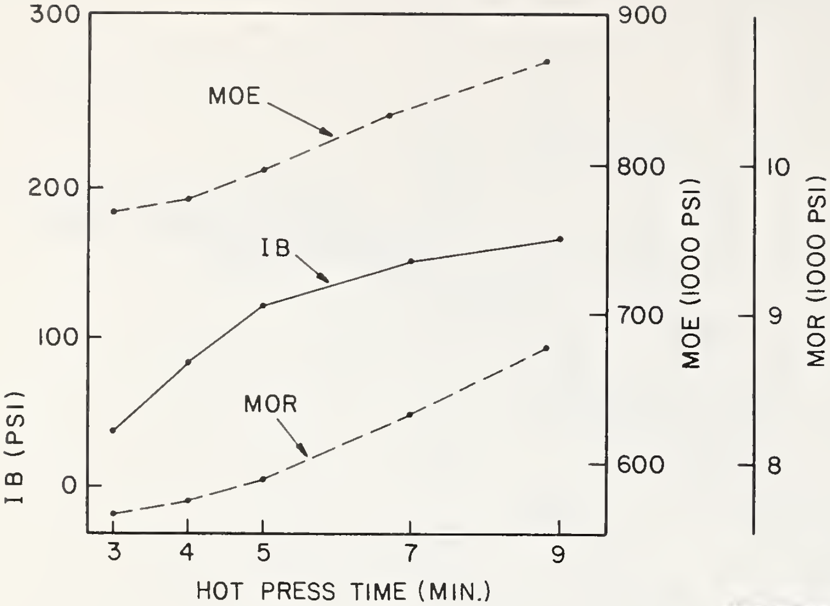

Figure 6. Effect of hot press time on IB, MOR, and MOE (with Hse's "Fast-Cure Phenolic Resin").

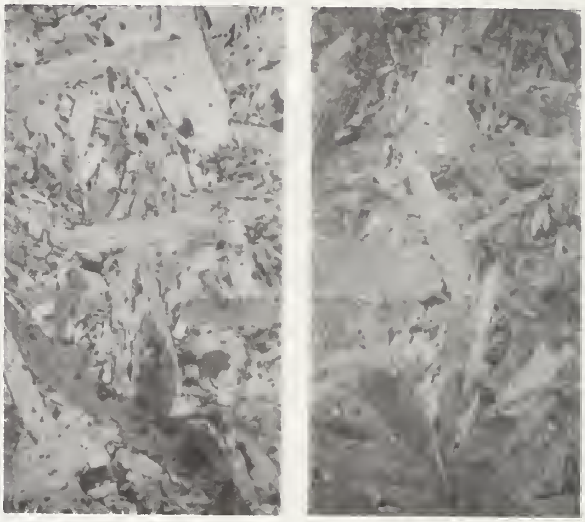

Figure 7. Mixed species hardwood flakeboard made in the laboratory (left) and in the mill (right) with Hse's "Fast-Cure Phenolic Resin").

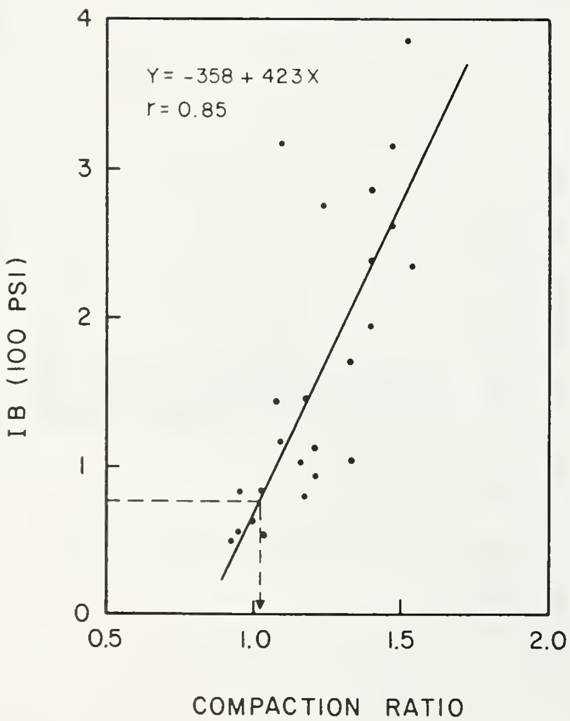

Figure 8. Relationship of compaction ratio to IB. Dashed lines indicate the compaction ratio corresponding to an attainable average of 70 psi IB.

ACCELERATED AGING OF PHENOLIC-BONDED FLAKEBOARDS

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Abstract

Specimens of phenolic-bonded flakeboard, vertical-grain southern pine and Douglas-fir, and marine-grade Douglas-fir plywood were exposed to four accelerated aging situations. These consisted of: (1) Multiple cycles of boiling and elevated-temperature drying, (2) multiple cycles of vacuum-pressure soaking and intermediate-temperature drying, (3) the six-cycle ASTM D-1037 exposure and, (4) continuous exposure to weathering at the Madison, Wis. site. Thickness change and bending strength, bending stiffness, and internal bond strength retention were measured after various numbers of exposure cycles, or time of exposure. The phenolic-bonded flakeboards retained enough strength and stiffness during accelerated aging to indicate they might be used satisfactorily in structural applications where conventional wood products are now used.

Introduction

The acceptance of new types of structural grades of flakeboard would be stimulated if suitable long-term service life can be demonstrated. The purpose of this study was to develop methods for assessing such service life and to apply these methods to evaluate selected prototypes of flakeboard from forest residues. This work was to determine the life-expectancy of phenolic-bonded flakeboard using accelerated aging by comparing its response with that of exterior-type plywood and of solid lumber.

There is much misunderstanding about accelerated-aging tests--the experimental techniques, analysis, interpretation of results, correlations, and objectives. But accelerated-aging tests are an essential step in the process of developing new products for use in critical, long-term applications. They can provide insight into degradation that could occur in service and thereby reduce the risk that an inadequate product might appear in the marketplace.

Evaluating a phenolic-bonded flakeboard for long-term performance is a different problem from that of evaluating a new adhesive system for its potential use in wood products. Structural flakeboard is made with an adhesive known to have excellent resistance to thermal degradation, to hydrolysis by moisture, and to the swelling and shrinking stresses a variety of acceptable wood products impose on the gluelines. These facts were responsible for selecting phenolics as the binder system in structural grades of flakeboard. The problem then, was to devise accelerated-aging tests to evaluate a bonded wood product for the retention of properties that are important in the intended end use.

The principal intended end use for structural flakeboard is for wall, roof, and floor sheathing where bending strength and stiffness are the important properties governing design and application. Because of this, bending strength and bending stiffness were the primary properties evaluated.

The intended end use also requires the product to resist the changing moisture conditions that arise in service. Because of this, phenolic-bonded flakeboard will be considered under requirements similar to those of exterior-type softwood plywood and not of the intermediate or interior types that are often used for sheathing purposes.

Background Review

Cyclic boil-dry treatments are most often used for evaluating weather-resistant products. This treatment maximizes the effect of three important influences that cause degradation--heat, moisture, and swelling and shrinking stresses. Boil-dry cycles are an empirical mixture of the three influences rather than any logical or intended simulation of a real-life situation. But repeated boil cycles have the potential to degrade weather-resistant products in the laboratory at a relatively rapid rate so that comparison between products can be made in a short time.

The accelerated-aging procedures in common use today for evaluating wood-based materials were developed primarily for quality-control purposes. In fact, ASTM D 1037 cyclic test for accelerated aging (1), which is a mixture of soaking, steaming, freezing, and drying through 6 cycles requiring 12 days, is the prescribed test in the product standard for Type 2 mat-formed wood particleboard (CS-236-66) (12). The West Coast Adhesive Manufacturers Association (WCAMA) (15,16) attempted to reduce the time required for this test by a 6-cycle procedure of vacuum-pressure soaking, boiling, and

drying to be completed in 6 days. This exposure and the D 1037 treatment are much more complicated and time-consuming than the single boil-dry-boil used for quality control in the manufacture of interior-type softwood plywood (PS-1-73) (13).

Shen and Wrangham (11) more recently reported on the development of a rapid accelerated-aging test also for quality-control purposes. They evaluated the 2-hour boil followed by wet testing, described in the German Standard DIN 68761 (5) for change in internal bond (IB) strength. This exposure was used in the Canadian Standard (CSA-0188-68) (3) but applied to bending specimens. Shen and Wrangham then correlated torsion shear testing with the more traditional IB test. But any of these quality-control tests provide only limited information--a two-point, before-and-after condition. They cannot be used for estimating the long-term performance.

There is little background information about how particleboard responds to exterior exposure--none of it extends for longer than 8 years. The WCAMA tests with board of unknown particle geometry showed MOR losses of over 50% in 5 years. The most extensive information on flakeboard durability was that by Hann, Black, and Blomquist (7,8) and Jokerst (9) at the Forest Products Laboratory. Weathering of phenolic-bonded flakeboards showed bending strength losses of 50 to 63% in 8 years at the Madison site. Clad and Schmidt-Hellerau (4) reported data for 3-year exposures on particleboards produced in Germany with alkaline-type phenolic adhesives. All of this work shows a general pattern of rapid loss of strength and stiffness during the first year or two of exposure with a much slower rate of loss in subsequent years, at least through 8 years.

Repeated boil-dry cycles to follow strength losses throughout a product's useful life are difficult to perform in the laboratory. A limited attempt to do this was made during the early development of the rate-process method of analysis (6). Specimens were carried through as many as 35 standard boil-dry-boil cycles (PS-1-74), but this was time-consuming and difficult to carry out manually during normal working hours. Attempts to develop machines to carry out cyclic tests automatically have been described in the literature from time to time with the most successful initiated at the Canadian Forest Products Laboratory in Vancouver (14). This equipment was further refined and extensively evaluated by the Weyerhaeuser Company (10). The developed method has been adopted as an ASTM Standard (D 3434, Multiple-Cycle Accelerated-Aging Test (Automatic Boil Test) for Exterior Wet-Use Wood Adhesives) (2). While the equipment was designed and used for evaluating standard plywood shear specimens, small lap specimens, and finger-joint specimens, modifications in design would adapt the unit to evaluate larger sized specimens such as flakeboard bending specimens. Any extended program of research involving cyclic accelerated aging of either products or adhesives would benefit from a machine of the Weyerhaeuser type.

Experimental Procedures

Materials

Flakeboard, plywood, and wood samples were selected for comparison. Each was assigned an alphabet identification that is referred to in the Results and Discussion and all tables and figures. These materials are described in Table 1.

Specimen Selection

Each material was cut into specimens 1/2 by 2 by 12 inches. Enough specimens were cut to carry out the planned treatments and sampling schedules. All specimens were conditioned to 80°F (65% relative humidity (RH)) prior to and after accelerated-aging exposures to achieve comparable moisture conditions at time of test. Specimens were mounted on racks designed to maintain a 1/4-inch space between them during the aging treatments.

Accelerated-Aging Exposures

Boil-dry exposure

Thirty specimens from each material were saturated with water by vacuum-pressure soaking and immediately placed in boiling water. There was sufficient stored heat to maintain boiling conditions when cold wood samples were placed in the bath. Distilled water was used in the bath to reduce scaling problems. After 10 minutes, the specimens were removed, allowed to drain momentarily, and then placed in an air circulating oven at 225°F for drying. At the end of 3-3/4 hours, the specimens were removed and weighed. The drying time was selected so that moisture content of the slowest drying material was reduced to 6 to 8%.

only before the first boiling treatment and not applied to subsequent cycles. Five randomly selected specimens were removed from each set for test after each of the prescribed cycles--1, 5, 10, 20, 40, and 80. Two cycles per day could be accomplished.

Vacuum-pressure-soak-dry exposure

Replicates of five specimens for each material were subjected to 1, 5, 10, 20, and 40 cycles of vacuum-pressure-soak-dry cycles. Each cycle consisted of 30

minutes at 29 in. Hg vacuum and 30 minutes of pressure at 60 psi submerged in tap water and 23 hours of drying in a forced-draft oven at 180°F. Weighing specimen sets before and after cycling assured that the slowest drying material was reduced to 6 to 8% moisture content during drying. One cycle per day could be accomplished.

Accelerated aging by ASTM D 1037

Five specimens for each material were subjected to accelerated aging by ASTM D 1037 accelerated-aging test procedures consisting of 6 cycles of the following sequence:

1. Soaking in water at 120°±3°F--1 hour.
2. Spraying with steam and water vapor at 200°±5°F--3 hours.
3. Storing at 10°±5°F--20 hours.
4. Drying at 210°±3°F--3 hours.
5. Repeating 2 above--3 hours.
6. Repeating 4 above--18 hours.

This procedure requires a minimum of 12 days and was carried on for each material, yielding only before and after values.

Outdoor exposure

Thirty individual specimens from each material were placed on an exposure rack at the Madison site. The specimens were attached with brass screws and exposed at an angle of 60° to the horizontal facing south. At various intervals of time, five randomly selected specimens from each set are planned for removal for test. After the first year of exposure, subsequent exposure periods will depend upon the extent of degradation each material already experienced, with the view to test all specimens of each type while specimen integrity is still maintained and reasonable rates of property loss can be measured.

Measurements and Physical Testing

Specimens were measured for thickness and width after conditioning at 80°F, 65% RH. The weight of specimen sets was measured before and after accelerated aging exposure and after conditioning at 80°F, 65% RH.

Each specimen was tested for bending strength, bending stiffness,[1] internal bond strength, and thickness swell. A span of 10 inches was used in the bending measurements.

Measurements of tensile strength perpendicular to the face (internal bond) were carried out on the ends of the specimens broken in the bending strength tests, selecting portions that received the least strain during bending.

Data Analysis

Bending strength and bending stiffness were calculated on the basis of original dimensions measured at 80°F, 65% RH, before exposure to accelerated aging. For unexposed materials, the mean and standard deviation were calculated for the replicates tested to provide an original property value and an indication of the variability in the unexposed materials. The mean value for replicates of exposed specimens was calculated and converted to a percentage of the property retained by comparison with the original mean value. Any change in variability that might have taken place during aging was found not to influence the general conclusions reached in this study.

The percentage change in each property obtained during accelerated aging was plotted against the number of cycles exposed. Inspection of a large number of these plots revealed a rapid property loss in the first cycle followed by a generally uniform slower rate of loss in subsequent cycles. Consequently, a linear regression line was calculated by the least squares method to provide an average rate of change of all specimens of each material subjected to accelerated aging. The values for unexposed specimens was not included in the calculations of the regression lines. Because of the limited number of replicates, the variability among specimens, and the limited objectives of this study, more sophisticated analysis of the data was unwarranted.

Results and Discussion

The properties of the unexposed materials evaluated are given in Table 2. The flakeboards at 0.60 to 0.64 specific gravity were generally more dense than plywood and solid wood at 0.47 to 0.50 specific gravity. Flakeboard bending strength ranged from about 2,658 psi to 4,927 psi, in contrast with plywood at 6,663 psi, Douglas-fir lumber at 14,346 psi, and southern pine lumber at 16,176 psi. Bending stiffness for the flakeboards was between 508 and 677 kpsi; plywood, 965 kpsi; Douglas-fir wood, 2,007 kpsi; and southern pine, 1,990 kpsi. The internal bond value of 127 psi for plywood was within the range of the values of 69 to 164 psi for the flakeboards, as compared with the much higher values of 372 psi for Douglas-fir wood and 612 psi for southern pine wood.

[1]The terms "bending strength" and "bending stiffness" are used because the specimens used in this study are smaller than the specimen specified in ASTM D 1037 (3 by 14 in.) for determination of modulus of rupture and modulus of elasticity of 1/2-inch-thick specimens.

The results of the accelerated-aging tests are shown in Figure 1 for bending strength response, in Figure 2 for bending stiffness, in Figure 3 for internal bond strength, and in Figure 4 for changes in thickness swelling. The figures include regression lines for each material subjected to the cyclic boil-dry and vacuum-pressure soak-dry treatments, each marked with the appropriate letter code. The results of the D 1037 test and the 1-year test fence exposure, providing single values for each material, are shown in the figures on a separate "percent retained" axis with the individual letter codes placed at the point of retention obtained.

With regard to bending strength, Figure 1, all accelerated-aging tests appeared to differentiate among the materials in the same way. The highest bending strength retention was obtained with solid wood and plywood. The four laboratory-prepared flakeboards were similar in their bending strength retention, which was generally at a somewhat lower level than solid wood and plywood. The lowest bending strength retention was shown by the commercially prepared waferboard, but it still retained 30 to 40% of its strength after the D 1037 test and after 40 cycles of vacuum-pressure-soak-dry or 50 cycles of the boil-dry test. The commercially prepared waferboard is believed to have a lower binder content than the laboratory-prepared flakeboards evaluated here. One year of test fence exposure reduced bending strength no more than 25% in all cases. For the flakeboards, 10 boil-dry cycles reduced strength more than 1 year on the test fence, while 10 cycles of the vacuum-pressure-soak-dry treatment reduced strength less than 1 year on the test fence.

The bending stiffness (Figure 2) of solid wood and plywood did not change appreciably during any of the accelerated-aging treatments. Stiffness appeared to increase slightly during the cyclic wetting and drying treatments with the lumber and plywood, and only 10% or less was lost by the D 1037 test or 1-year test fence exposure. The four laboratory-prepared flakeboards lost stiffness with wet-dry cycling but still retained 70 to 80% after 80 boil-dry cycles or 80 to 90% after 40 VPS-dry cycles. The D 1037 test and 1 year of test fence exposure produced bending stiffness losses about equivalent to those caused by 50 to 60 boil-dry cycles and 40 VPS-dry cycles. Again, the commercially prepared waferboard lost bending stiffness to a greater extent than did the other materials evaluated, but still retained more than 40% under the most severe treatment, 80 boil-dry cycles.

The internal bond strength (Figure 3) was the strength property undergoing the most change during accelerated aging. Even the D 1037 test produced a 20% loss in internal bond with solid wood and plywood. This loss was equivalent to the loss after 10 to 20 boil-dry and VPS-dry cycles. Continued cycling produced drastic reductions in internal bond strength with all materials evaluated, with the greatest loss being exhibited by the commercially prepared waferboard. One-year exposure on the test fence produced only moderate losses of internal bond strength with the flakeboards (60% or better retention) and little change in Douglas-fir and plywood.

The southern pine lumber, after exposure to the D 1037 conditions, yielded lower internal bond strength than expected. Southern pine lumber became noticeably checked in all accelerated tests and posed experimental problems during testing, especially in internal bond strength measurements.

There appeared to be some differences among the four laboratory-prepared flakeboards with regard to internal bond retention, variances which were not differentiated by either bending strength or stiffness measurements. The residue flakeboard B lost internal bond strength to a greater extent than did flakeboard A which had been prepared with a higher binder content. Flakeboard L, similar to flakeboard B but prepared from a different residue mix, lost internal bond strength at a rate intermediate to that exhibited by flakeboards A and B. The removal of fines from flakes to produce flakeboard O appeared to have little effect on internal bond retention in either the boil-dry cycles or the D 1037 test. There was a hint of improvement caused by fines removal with the VPS-dry treatment, but it is highly unlikely that the noted difference is statistically significant considering the variability in the data.

As expected, there was little residual thickness swelling (Figure 4) with the two solid wood samples or plywood in any of the accelerated-aging treatments. Of these, the 4% thickness swelling of plywood was the greatest. All laboratory-prepared flakeboards exhibited thickness swelling ranging from about 14% to 27%, and the commercially prepared waferboard swelled over 40% after 80 boil-dry cycles. The boil-dry cycles caused most of the thickness swelling during the first few cycles, with only minimal changes thereafter. The VPS-dry cycles caused less swelling during the first few cycles. The swelling gradually increased to about the same swelling after 40 VPS-dry cycles that was obtained after 1 to 5 cycles of the boil-dry treatment. The D 1037 produced about the same thickness swelling as 1 to 5 boil-dry cycles or 40 VPS-dry cycles, with the exception of the waferboard.

Thickness swelling after 1-year test fence exposure was no greater than 10%, in all cases.

The test fence exposures were considered to be an accelerated treatment because individual test specimens, rather than panels were exposed in a position to provide maximum opportunity for wetting and drying. After 1-year exposure, two laboratory-prepared flakeboards (A and B) retained 83 and 91% bending strength and 90 and 71% internal bond strength, respectively. Previous outdoor exposure tests (7,8,9) had involved panel exposure in a vertical position facing south and strength test specimens were cut from panel centers with the edges discarded--a much less rugged exposure. A flakeboard bonded with 6% phenolic resin and no wax, when exposed in this fashion for 1 year, retained 52% bending strength and 47% internal bond strength. After 8 years' exposure these values decreased only to 48% bending strength retention and 33% internal bond strength retention. Comparing these results with those from the present study where fence exposure degradation was accelerated suggests that the phenolic-bonded flakeboards should perform well for many years during outdoor weathering. Results of strength tests after additional years of exposure will be needed to verify this indication.

Significance of This Work

The results of these accelerated-aging tests, provide confidence that phenolic-bonded flakeboards manufactured from forest residues would serve well in many structural applications. They retained a respectable level of bending strength and stiffness when exposed to soaking and drying so severe that even solid lumber and marine-grade plywood, whose performance is well recognized, suffered appreciable losses.

A comparison of the accelerated aging procedures suggests that multiple cycles of boiling and drying, capable of automation, could detect differences in material behavior in a manner similar to that produced by the standard, but more complicated, method.

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TABLE 1. -- DESCRIPTION OF 1/2-INCH BOARD MATERIALS.

	Material	Species	Flake	Board weight	Phenolic resin	Wax	Press conditions: Press temperature	Press conditions: Time to thickness	Press conditions: Press time
			In.	Pcf.	Percent	Percent	°F	Min.	Min.
A	FPL flakeboard	Douglas-fir	0.015 x 1 random width	40	6	1	350	1	10
B	FPL residue mix (15-70-15 weight)	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	40	5	1	350	1	10
C	Commercial waferboard	Aspen			Yes				
L	FPL residue mix (15-70-15)	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	44	5	1	350	1	10
O	FPL residue mix (15-70-15) fines removed	Douglas-fir	faces 0.02 x 1 x 2 disk core 0.05 x 2 random width ring	41	5	1	350	1	10
P	Commercial plywood	Douglas-fir			Yes				
W	Heartwood	Douglas-fir							
X	Sapwood	Southern pine							

TABLE 2. -- PROPERTIES OF UNEXPOSED MATERIALS.

Material	Specific gravity	Thickness	Bending strength[1]	Bending stiffness[1]	Internal bond[1]
		In.	Psi	Kpsi	Psi
A-FPL flake	0.64	0.51	4,927 (760)	677 (70)	164 (20)
B-FPL residue flake	.61	.52	3,799 (650)	608 (57)	83 (21)
C-Commercial wafer	.60	.53	2,658 (335)	508 (34)	69 (12)
L-FPL residue flake	.63	.52	4,588 (1,117)	711 (104)	107 (16)
O-FPL residue flake	.62	.52	4,886 (667)	670 (26)	125 (21)
P-Plywood	.47	.48	6,663 (915)	965 (180)	127 (24)
W-DF wood	.48	.50	14,346 (1,900)	2,007 (276)	372 (66)
X-SP wood	.52	.50	16,176 (1,937)	1,990 (366)	612 (89)

[1]First value is mean for 10 specimens tested for materials A, B, C, P, W, and X, and for 5 specimens for L and O. Value in parentheses is standard deviation.

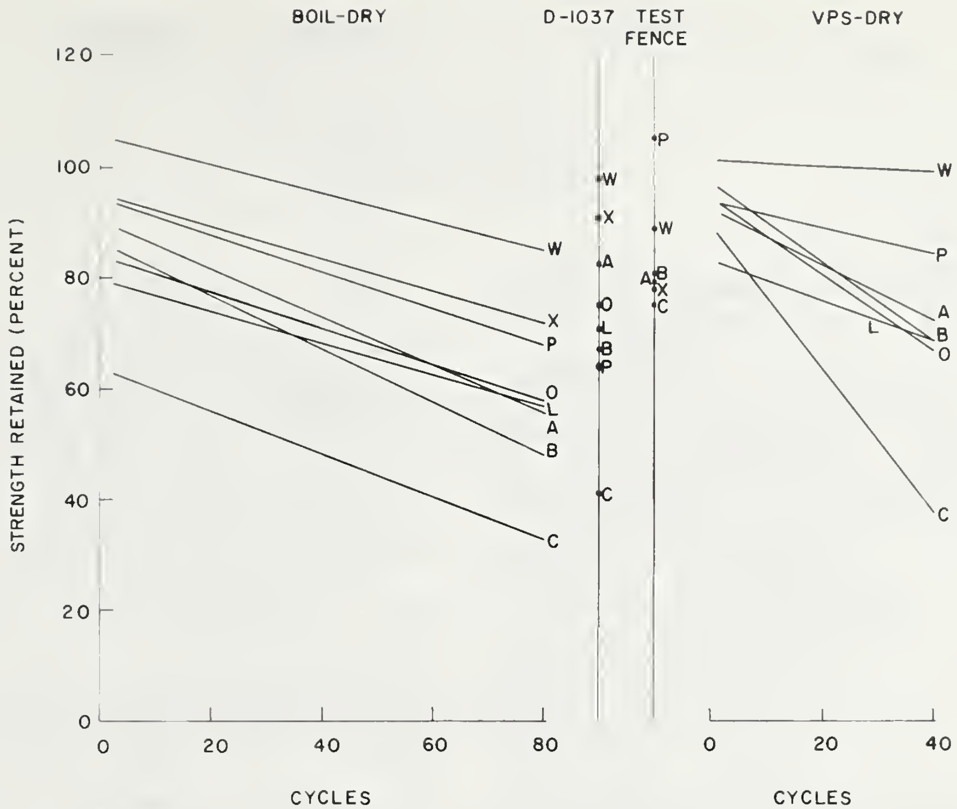

Figure 1.--Bending strength of material. A, B, C, L, and O are flakeboards, P is plywood, and W, X are from solid wood (see Table 1 for identification).

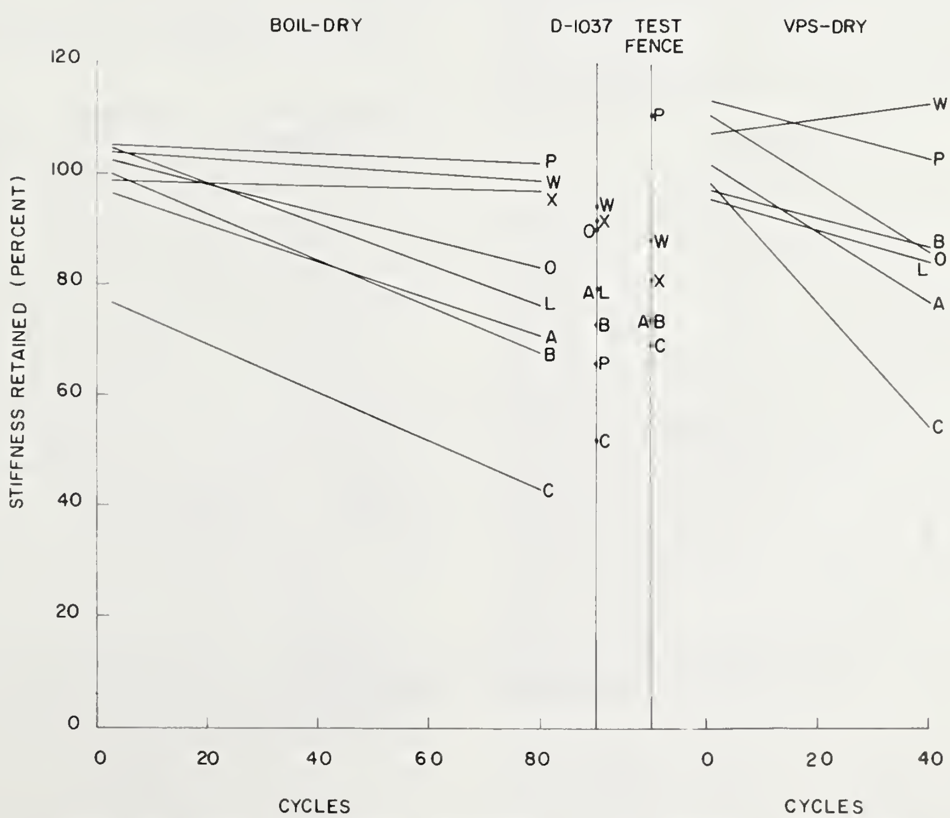

Figure 2.--Bending stiffness of material. A, B, C, L, and O are flakeboards, P is plywood, and W, X are from solid wood.

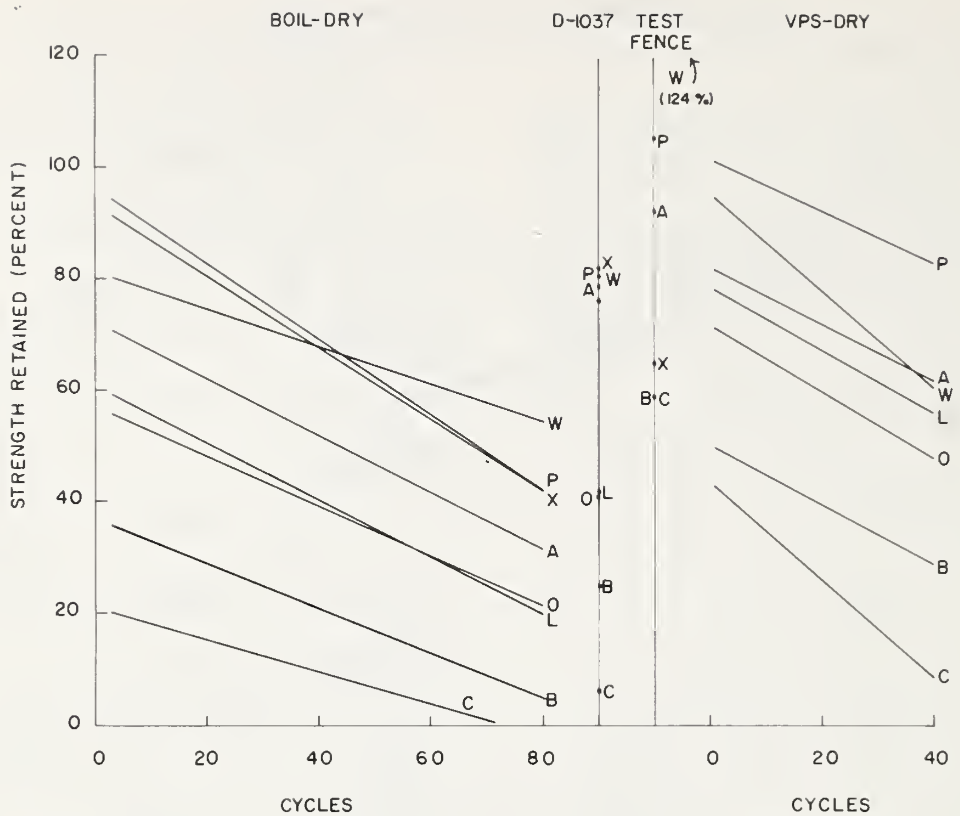

Figure 3.--Internal bond of materials. A, B, C, L, and O are flakeboards, P is plywood, and W, X are from solid wood.

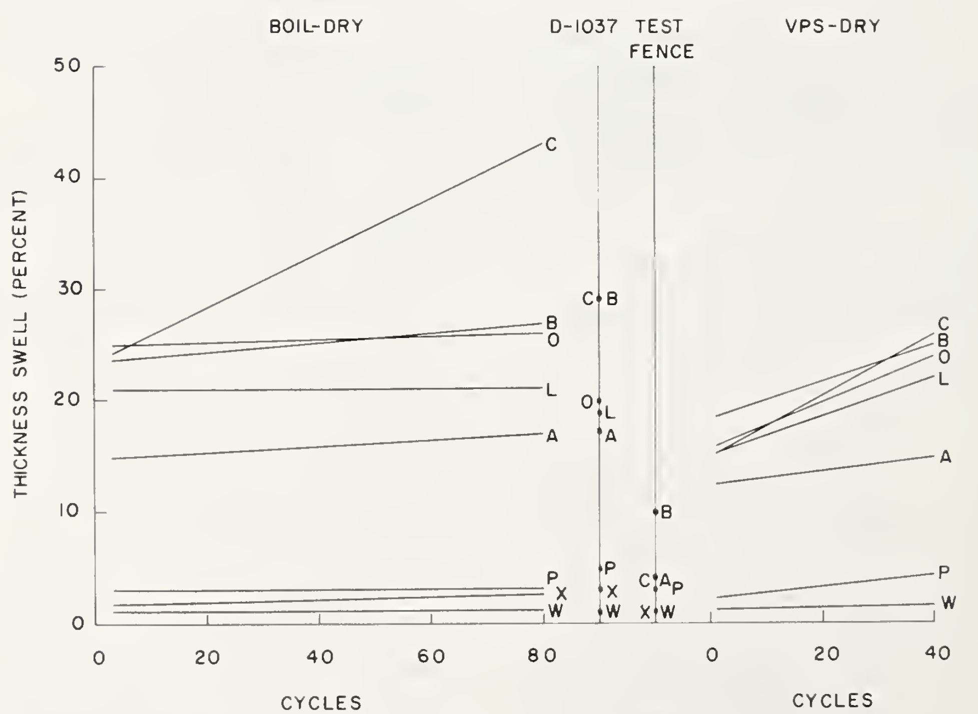

Figure 4.--Thickness swell of material. A, B, C, L, and O are flakeboards, P is plywood, and W, X are from solid wood.

PROPERTIES OF FLAKEBOARD PANELS MADE FROM SOUTHERN SPECIES

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Abstract

Structural exterior flakeboards manufactured with phenolic resin and flakes produced on a shaping-lathe headrig were evaluated for plate shear modulus, internal bond, bending properties, uniform loading, concentrated loading, and impact resistance. Both mixed- and single-species 4- by 8-foot flakeboards were produced. Panels with mixed flakes had 20 percent by weight of hickory, white oak, southern red oak, sweetgum, and southern pine. The variables in fabricating these panels were:

1. Aligned (oriented) face and core flakes in panels of two densities and thicknesses of 1/2 and 5/8 inch.

2. Randomly oriented (random) face and core flakes in panels of two densities and thicknesses of 1/2 and 5/8 inch.

Single-species, 1/2-inch-thick boards of one density class were fabricated with random flakes of yellow-poplar and loblolly pine.

Regression equations for the mixed species panels indicated that at 46 pcf density, a shear modulus of 192,000 psi would be obtained for the oriented panels. Random panels of this density would have 35% larger shear modulus. Based on a specimen's initial dimensions, 70% of the bending strength was retained, while the modulus of elasticity increased after accelerated aging exposure. Initial bending properties depended on panel direction tested and on flake orientation. Oriented panels stressed along the 8-foot axis had the highest bending strength (5,412 psi for 1/2-inch panels); bending strength across the 4-foot width was lower (3,346 psi). Modulus of elasticity was more affected by flake alignment than was bending strength. In oriented panels modulus of elasticity was 967,000 psi along the 8-foot axis and 377,400 psi across the panel; random panels stressed along the 8- and 4-foot axis had bending strengths of 5,034 psi and 4,214 psi and moduli of elasticity of 710,400 psi and 554,000 psi. When bending strength and modulus of elasticity were averaged over both directions, the oriented panels averaged higher than the random panels. Internal bond of all panels after accelerated aging exposure decreased from the initial acceptable internal bond (greater than 70 psi) to below 30 psi.

For 200- and 300-pound concentrated loads applied 2-1/2 inches from the edge on 1- and 3-inch disks, respectively, oriented and random panels had similar deflection values. However, failure loads applied on the disks were higher for the random panels than for the oriented panels. Also, the random panels retained more strength after a 3-day water spray than the oriented panels. In general, the oriented panels deflected less than random panels in tests of distributed load over a 24-inch span. For a 16-inch span, dry-tested 5/8-inch random panels deflected less than oriented panels.

Oriented and random mixed species flakeboard had less impact resistance than southern pine plywood. Oriented flakeboards of 1/2-inch thickness had less impact resistance than random flakeboards of this thickness. In 5/8-inch thickness, random mixed species flakeboards tested wet had greater impact resistance than oriented flakeboards; when tested dry, oriented boards of this thickness had greater impact resistance.

Introduction

The Southern Forest Experiment Station's efforts at using forest residues for structural flakeboards focuses on underused hardwoods growing on southern pine sites. Hse et al. (1975) indicated that two methods of constructing three-layer pressed boards made from flakes produced on a shaping-lathe headrig could probably meet use requirements and Forest Service goals (Schaffer 1974). In the first of these constructions (random), flakes are randomly oriented throughout the board; in the second (oriented), flakes on face and back are aligned with one axis of the board, while core flakes are randomly placed. Test panels 18 inches square and 1/2-inch thick were fabricated in the laboratory according to the specifications proposed by Hse et al. The panels' strength properties are tabulated on the following page.

Small test panels were fabricated with relative ease; it is more difficult, however, to lay up and press commercial 4- by 8-foot panels. Research indicated that the larger panels could be fabricated; but, a small percentage decrease in strength properties should be expected

Board property	Oriented	Random
Board density, pounds per cu. ft.	45.5	47.5
Modulus of elasticity (MOE), psi	1,090,000	800,000
Bending strength, psi	6,600	5,300
Internal bond, psi	82	83

(Price 1975). Commercial production might therefore require heavier or thicker boards to compensate.

In this study 4- by 8-foot panels of various densities and thicknesses were fabricated. Evaluation of plate shear, bending, internal bond, and 24-hour water soak specimens cut from the 4- by 8-foot boards are discussed in Part I. The second section discusses panel behavior under concentrated, distributed, and impact loadings of 4- by 4-foot sections.

Experimental Procedure

Fabrication

Panels were a mix of 20% each by weight of hickory (*Carya* sp.), white oak (*Quercus alba* L.), southern red oak (*Q. falcata* var. *falcata*), sweetgum (*Liquidambar styraciflua* L.), and southern pine (*Pinus* sp.). Flake and panel specifications are in Table 1. The 4- by 8-foot panels were manufactured with: (a) random face and core flakes and (b) oriented face and core flakes. Also, 4- by 8-foot, single-species, random-flake panels were fabricated using either yellow-poplar (*Liriodendron tulipifera* L.) or loblolly pine (*Pinus taeda*). Mixed species panels were made 1/2- and 5/8-inch thick; those of single species were made in the 1/2-inch thickness only.

Random panels were batch formed with a commercial resin at the U.S. Forest Products Laboratory, Madison, Wisconsin. The panels were pressed two at a time in a single-opening press 20 feet long. Both 1/2- and 5/8-inch boards were pressed at 350°F and 575 psi. Press time for the 1/2-inch board was 7.5 minutes; for the 5/8-inch, 9.5 minutes. The FPL press had a 15- to 20-second pause between the time of contact of the top platen with the mat and the time pressure commenced. Because of this pause, a top caul was used to retard heat transfer and precure.

Oriented panels were fabricated with specially formulated resin (Hse 1976) in the pilot plant of Potlatch Corp. at Lewiston, Idaho. The panels were made in a double-opening press 8.5 feet long. These 1/2- and 5/8-inch panels were pressed for the same amount of time as the random panels, 7.5 and 9.5 minutes, but at lower temperature and specific mat pressure--340°F and 450 psi.

Density

Panel density depended on the method of fabrication, flake orientation, and species mixture. Panel density, in pounds per cubic foot (pcf), was based on weight and volume at about 6% moisture content. Twenty-eight random panels were fabricated at each of the following densities.

Species	Panel thickness 1/2-inch	5/8-inch
	(pcf)	
Mixed species	47, 49	45, 47
Yellow-poplar	43.5	--
Loblolly pine	45.	--

Because the equipment used to form the oriented panels caused substantial variation (as high as 10 pcf) among the panels, each thickness group was sorted into two average density classes containing 27 panels:

Thickness	Density
1/2-inch	46.6, 51.3
5/8-inch	45.6, 47.9

The densities of specimens cut from panels and used in the tests are reported on an ovendry basis and are somewhat less than the densities of the full-size panels.

Tests

From each density group, eight panels were chosen at random and cut into two 4-foot-square sections. One section was reserved for the concentrated and distributed load tests discussed in part II. The other 4-foot section was dissected into small-size test specimens (Fig. 1).

Plate shear specimens, 17.5 inches square, were tested according to ASTM D 3044-72 (ASTM 1974). Bending, internal bond, and 24-hour water soak tests were conducted according to ASTM D 1037-72 (ASTM 1974), with the addition of a modified aging test.

Four sets of three bending specimens were taken from each 4- by 4-foot section of panel (Fig. 1). From each set, an original-condition (65% RH at 72°F), accelerated-aging, and modified aging specimen was randomly selected. Fifteen-inch test spans were used for 1/2-inch-thick bending specimens, and 18-inch spans, for 5/8-inch specimens.

Internal bond specimens used for the 65% RH, accelerated aging, and modified aging tests were removed from bending

specimens. Internal bond samples used for the 50% RH test were cut from the 4- by 4-foot sections of panel (Fig. 1).

The modified-aging regime consisted of three complete cycles of:

1. Immersing in water at 120°±3°F for 6 hours.

2. Heat in dry air at 210°±3°F for 18 hours.

Before testing, material was conditioned at 72°±3°F and RH of 65°±1% for at least 1 week.

Statistical Analysis

Linear regressions were used for comparing board constructions and thickness. All differences were statistically significant at the 0.005 level of probability. When comparing properties that have a significant linear relationship with density, comparisons are made at 46 pcf densities for mixed-species panels and 42 pcf for single-species panels.

Results

Plate Shear

At a density of 46 pcf, the shear modulus of the random panels, 259,000 psi, is 35% higher than that of the oriented panels, 192,000 psi. The regression slopes of panel density on shear modulus are statistically equivalent for both 5/8-inch panels and the 1/2-inch random panel (Table 2). Since the slope of the 1/2-inch oriented panels was not equivalent to the 1/2-inch random panel, at higher or lower densities the 35% difference in shear moduli will not be maintained.

Bending

Based on regressions calculated for a density of 46 pcf (Table 3), oriented panels have better bending properties than random panels if both the 8-foot and 4-foot directions are averaged, even though oriented panels were pressed at lower pressure and cold-cut flakes were used. In the 8-foot direction, oriented panels have better bending properties than random panels; in the 4-foot direction random panels have the better bending properties (Table 4). The directional effects held for both 1/2- and 5/8-inch thicknesses. Bending properties of 1/2-inch mixed species panels were lower than those of 5/8-inch panels.

When directional property ratios (DPR), that is, the bending strength or modulus for the 8-foot direction divided by that for the 4-foot direction, equals 1.0, complete randomization is achieved. The higher the ratios, the better the orientation. The DPR of 5/8-inch panels was greater than that of 1/2-inch panels, indicating an increase in directional property difference with increased thickness.

Random mixed species panels had DPR's of 1.15 in bending strength (MOR) and 1.21 in modulus of elasticity (MOE). Single-species panels averaged 1.21 and 1.26 for MOR and MOE. These DPR's indicate that the forming system at FPL caused a small degree of orientation.

Oriented panels had a DPR of 1.79 in bending strength and 2.70 in MOE, so Potlatch's orienting equipment was successful in orienting the flakes. Visual analysis indicated that the oriented panels' DPR was influenced by two factors. First, the alignment mechanism for core flakes functioned better than the mechanism for face flake alignment. Second, a consistent feed rate at the mat forming station could not be obtained, resulting in an unbalanced core-face ratio.

In general, modified aging did not reduce bending properties as much as the ASTM accelerated aging (Table 5). For the mixed-species panels at 46 pcf, 60% and 78% of the bending strength was retained after accelerated and modified aging, respectively. Single-species panels retained 93 and 95% of their bending strength after aging exposures.

Since MOR and MOE after aging are based on the specimen's original dimensions, substantial swelling during aging may indicate either a loss or gain in strength and stiffness, which is reflected mostly in the MOE values (Table 5).

Internal Bond

The internal bond (IB) at 46 pcf was not affected by the orientation of the flakes (Table 6). Internal bond was affected by thickness and was the only property tested for which 1/2-inch boards had better values than 5/8-inch boards. However, internal bond of the 5/8-inch boards could be improved by a longer press time and greater pressure. Also, face densification on all panels could have been improved by greater pressure.

The pressing schedules used did not significantly densify the face of the panels, which yielded a uniform density profile throughout the panel thickness. Most IB failure of mixed-species panels, regardless of exposure condition and panel thickness, occurred in the face flakes (Table 7). Because of the uniform density profile, sanding before testing would probably not have decreased the incidence of face-flake failures. The experimentally determined linear relations (Table 6) indicated that to obtain an IB strength of 70 psi, density of 1/2-inch mixed species panels must exceed 43 pcf and

5/8-inch panels must exceed 47 pcf.

As exposure induced weathering or moisture increased, IB decreased (Table 8). Increasing RH from 50 to 65% decreased IB an average of 7.6 psi because of moisture increase or density decrease or both. Modified aging and accelerated aging reduced IB strength drastically. The average modified aging strength (13.5 psi) is only 21% of the 65% RH average. Accelerated aging reduced the IB an additional 8%. For the mixed-species panels, only 10% of the 65% RH strength was retained after accelerated aging, but the single-species panels retained 28%. An improvement in aged IB should improve other properties and may decrease the property differences discernible after modified and accelerated aging exposure.

24-Hour Soak

Linear regressions on density of percent water absorbtion based on weight gain (WAW), and percent thickness swell per percent moisture content increase (TM) were significant for mixed-species panels. Comparisons among regressions (slopes) indicate that panel thickness did not affect the density relationships. But, flake orientation was significant. Combining the panel thicknesses for each flake orientation, linear regressions for WAW and TM on density (ρ) are:

Panel type	Linear regression	R^2	$Sy\cdot\rho$
Random	$WAW=70.37-1.12\rho$	0.663	2.651
	$TM=-3.78+0.183\rho$	.553	.546
Oriented	$WAW=99.81-1.48\rho$	.537	4.267
	$TM=-2.35+0.136\rho$	.350	.608

The dimensional stability was influenced by the fabrication variables. Random panels' linear expansion (LE) is larger in the 4-foot direction, while the oriented panels have the largest LE's in the 8-foot direction (Table 9). As previously discussed, equivalent layer orientation or randomization and balanced layer flake quantity was not obtained. If the three-layered mats had been fabricated with cores and faces of equal weight and equally well aligned, then the linear expansion values would have been equal in both directions.

Concentrated and Distributed Load Evaluation

Test Procedure

The eight 4-foot-square sections per density group that remained after the original 4- by 8-foot panels were cut, were randomly divided into two groups. The sections were tested for concentrated and distributed loads; one group was tested on 16-inch joist-type spacing and the other on 24-inch spacing. Panel sections used for the 24-inch spacing were cut in the panel's original 8-foot direction to yield two 2- by 4-foot pieces. Panels for the 16-inch spacing were obtained by removing 16 inches from the inside edge (an edge that had been part of the interior of the original 4- by 8-foot panel) of a 4- by 4-foot section, and then cutting the section in half in the 8-foot direction. This left two 24- by 32-inch sections for testing. One piece of each section to be used for the 24-inch and 16-inch spacings was designated for a wet test; the other, for a 50% RH test (dry).

For the wet test, panels were exposed to a continuous 3-day water spray applied to the top surface (loading surface) of the panel. While they were sprayed, panels were inclined vertically. Spray heads were calibrated to apply about 6 gallons of water per hour to each panel. After the spray, panels were nailed to framing members and evaluated within 8 hours for initial concentrated load deflections, distributed load, and concentrated load to failure in the same sequence as the dry test panels.

All panels were nailed to nominal 2- by 8-inch, kiln-dried, No. 2 (or better) grade, southern pine framing (Fig. 2); the 8-foot dimension of the panel spanned the framing members. Panels were attached with 8d common nails spaced about 6 inches on center and about 3/8 inch from the edge along outside framing members. Nails were 12 inches on center on the middle framing member. A nominal 1- by 4-inch board was nailed to the lower part of each end of the frame to prevent rotation of the structure.

For the concentrated load test of panels on 24-inch spans, a disk 3 inches in diameter was placed at mid-span 2-1/2 inches from the panel's outside edge (an edge on the outside of the original 4- by 8-foot panel) (Fig. 2). A 300-pound load was applied to the disk at 0.20 inch per minute. Once the 300-pound load was removed, a 1-inch disk was placed 2-1/2 inches from the edge, directly across the span from the first load. A 200-pound load was applied to the disk at 0.20 inch per minute. Next, the load was removed and another 200-pound load on a 1-inch disk was applied 2-1/2 inches from the same edge as the original 300-pound load but on the opposite span. The final load was 300 pounds on a 3-inch disk applied to the remaining edge.

For testing the 16-inch spans, a 200-pound load was applied first, then two 300-pound loads, and a final 200-pound load. In all cases, deflection of the underside of the panel at the point of load was continuously recorded. The

deflection measuring device was fastened so that deflection readings were relative to the joists.

Within a few hours after the concentrated load tests, 2,000-pound distributed loads were applied twice to the panels. With each load, panel deflection at the center of span was recorded relative to the joist.

After the distributed load test, the panels were subjected to concentrated loads to failure. Procedures for loading the panels were the same as those used in the earlier concentrated load tests.

Results and Discussion

The only failure in all of the concentrated load tests was a low density 1/2-inch oriented mixed species panel evaluated under the wet condition. The load was applied to this panel as a 3-inch disk and was located next to an outside edge. Failure occurred at 260 pounds.

When the inside and outside edge values and both densities (highest two density groups for 5/8-inch random mixed species panels) were averaged, the oriented and random panels had statistically equivalent (0.05 level) deflections for equal thicknesses (Table 10). The largest differences between random and oriented panels occurred in the wet test. In this test, the deflection of oriented panels exceeded that of random panels for all 24-inch spans and one 16-inch span.

Failure loads on random panels significantly exceeded failure loads on oriented panels under wet and dry conditions. Also, the random panels retained more of their dry strength. For example, the 24-inch-span, random panels evaluated wet retained 81% of their dry strength, oriented panels retained 74%. For 16-inch spans, random panels retained 74% and oriented panels retained 62% of their dry strength. In fact, for the 24-inch span, the failure load of the random panels when wet was about equal to the failure load of the oriented panels when dry.

Oriented panels usually deflected less and sustained more weight when a load was applied near the inside edge than when it was applied near the outside edge (Table 11). Although the case was not as clear for random panels, the outside edge tended to be stronger than the inside. In most cases, as the density of random panels increased deflection diminished and maximum load rose. In contrast, several cases occurred where 1/2-inch oriented panels evaluated on 24-inch spans deflected more and supported less weight as panel density increased.

All 1/2-inch panels evaluated on 24-inch spans deflected less than 0.25 inch when dry tested and more than 0.35 inch when wet tested. The 5/8-inch panels on 24-inch spans had less than 0.25-inch and 0.38-inch average deflection for dry and wet tests. By increasing panel thickness from 1/2 to 5/8 inch, panel deflection for 200- and 300-pound loads was reduced about 40% for both wet and dry conditions. Failure load, applied on 1- and 3-inch disks, increased at least 25% with the 1/8-inch increase in panel thickness. The relationships held for the 16-inch spans except for maximum load applied to wet panels on a 3-inch disk.

By decreasing the span from 24 inches to 16 inches, the deflection caused by a 200-pound load applied on a 3-inch disk decreased 2.5 times for the dry test and 2.3 times for the wet test. The shorter span also increased the weight of failure loads, the amount depending on the loading disk, test condition , and panel construction. In general, dry-test load on panels increased 21%, and wet-test load increased 19%.

The 200-pound uniform load equalled 250 pounds per square foot (psf) on panels nailed over 24-inch spans and 375 psf on panels nailed over 16-inch spans. Although the longer span supported less weight per square foot, the deflection ratio of 24-inch to 16-inch spans was 5.0 for the dry test and 5.7 for the wet test. For the 24-inch span, random mixed species panels deflected more than oriented panels under wet and dry conditions. The 1/2-inch random and oriented panels deflected about the same when dry-tested on 16-inch spans. In the wet-test, 1/2- and 5/8-inch random panels deflected more than oriented ones. The 5/8-inch random panels deflected less than oriented panels when dry tested.

Impact

Procedure

Six panels from each density group were chosen at random for impact evaluation. The only 5/8-inch random mixed species panels used were from the two low-density groups. Nineteen southern pine plywood panels of two thicknesses (1/2-inch with three plies and 5/8-inch with four plies) were purchased from six building suppliers in central Louisiana. A 1/2-inch and 5/8-inch panel from each supplier was randomly selected for impact evaluation.

All 1/2-inch panels were cut into 4- by 4-foot sections; 5/8-inch panels were cut to obtain one 48- by 32-inch piece from each end. One section was used for dry test (50% RH condition). The other section was designated for a 3-day water spray before evaluation. The water-spray cycle consisted of the same regime

as in the concentrated-load test, and all panels were nailed to frames as described in the concentrated-load section. All 1/2-inch panels were evaluated on 24-inch spans; the 5/8-inch panels were evaluated on 16-inch spans.

Both spans of each panel were tested. Impact locations were at mid-span 6 inches inward from the edge (Fig. 3). A 200-pound load was applied to a 3-inch disk at the designated impact location before each drop of the impact load and after failure. The deflection resulting from the concentrated load was recorded relative to the joist. After removal of the concentrated load, a leather bag containing enough No. 9 lead shot to total 30 pounds was released by a remote-controlled solenoid-activated pair of jaws. The drop bag conformed to ASTM E 72-68 (1968). The first drop height was 6 inches and height was increased in 6-inch increments until the panel would not support the 200-pound load or a failure was observed. The maximum drop height (MDH) was recorded, and the deflection caused by each drop was recorded relative to the joist.

Results of Impact Test

Southern pine plywood had greater average impact resistance than any of the flakeboard panels (Table 12). However, yellow-poplar flakeboards that were wet tested had a higher impact resistance than plywood that was wet tested. Only the 1/2-inch oriented mixed species flakeboards had a deflection at maximum drop height that was less than that of plywood.

Considerable variation was observed in the impact resistance of different plywood panels and between locations on one panel. For instance, the 5/8-inch plywood that was dry-tested had an average MDH on the inside edge of 56 inches (range of 18 to 90 inches) and an average on the outside edge of 84 inches (range of 66 to 120 inches) (Table 13). The 1/2-inch plywood had a more consistent average MDH (64 inches for both edges), but the range was 36 to 78 inches for the outside edge and 12 to 102 inches for the inside edge.

Among flakeboards, yellow-poplar panels had the greatest and 1/2-inch oriented panels the least impact resistance. Results for random pine panels were similar to those for random mixed species panels. The 5/8-inch random flakeboard had a higher MDH than similar oriented flakeboard for the wet test but a lower MDH for the dry test. The difference may have occurred because of excessive thickness swell and water absorption by the oriented panels.

Except for yellow-poplar flakeboards, the impact resistance and deflection of 1/2-inch panels in the dry test were similar to those in the wet test. Among 5/8-inch panels, the random panels and plywood had more impact resistance when wet than when dry tested. Oriented panels and plywood deflected more when wet tested than when dry tested.

After impact failure, all panels supported the 200-pound concentrated load. Except for a few cases, the deflection ratio--final deflection/initial deflection --exceeded 1.50 but was greater than 1.86 only for the wet 5/8-inch oriented mixed species flakeboards. Among 1/2-inch panels, plywood had the lowest deflection ratio for both wet and dry conditions. But the ratio for 5/8-inch random flakeboard was less than that for 5/8-inch plywood for the dry test and equal for the wet test.

The 200-pound concentrated load caused less initial deflection for all types of flakeboards than for plywood when equal thicknesses were compared. After failure, the plywood deflected slightly less than flakeboard of equal thickness except for the dry tested 1/2-inch yellow-poplar flakeboards and wet tested 5/8-inch oriented mixed species flakeboards.

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7. Schaffer, E.L. 1974. Forest residue into structural particleboard: A Forest Service national program. American Society of Agricultural Engineers Paper No. 74-1548, p. 21.

Table 1.--Flake and panel fabrication specifications for 4- by 8-foot structural flakeboards

Property	Specifications
Flake generation	From 6-inch bolt on shaping lathe
Flake length	3 inches
Core flakes	0.025 inch thick, milled for width reduction
Face flakes	0.015 inch thick, random bolts heated to 160°F oriented bolts at ambient temperature
Flake moisture content	3 to 4%
Mat construction	Layered with each face 1/4 of total weight
Surface treatment	Sprayed 4.32 g of water per square foot of surface area
Resin binder	6% liquid phenol-formaldehyde resin 1/
Wax	1% wax solids from wax emulsion

1/ Hse, C.-Y. 1975. Formulation of an economical fast-cure phenolic resin for exterior hardwood flakeboard. Proceedings of the 9th Particleboard Symposium, Pullman, Wash.

Table 2.--Summary of shear modulus and regression equations

Flakeboard panel type	Number of test specimens	Moisture content	Density ρ 1/	Shear modulus G	Linear regression, $G = a + b\rho$			
					a	b	R^2	$Sy\cdot\rho$
		%	pcf	thousand psi				
1/2-inch oriented mixed species	16	10.34	42.55	173.84	- 90.157	6.131	0.840	8.395
	16	9.78	46.85	193.95				
1/2-inch random mixed species	16	10.24	46.31	261.57	-122.291	8.302	.670	13.213
	16	10.17	48.00	276.80				
5/8-inch oriented mixed species	16	10.02	41.09	155.41	-155.924	7.573	.861	9.855
	16	10.30	45.48	188.40				
5/8-inch random mixed species	16	10.01	42.60	235.94	- 91.683	7.622	.777	12.601
	16	9.99	45.46	252.52				
	8	10.20	49.48	288.24				
1/2-inch random pine	16	10.66	41.95	266.89	N.S.			
1/2-inch random yellow-poplar	16	9.50	42.25	301.30	N.S.			

1/ Density based on OD weight and volume at test.

Table 3.--Regression relationship between density and bending properties.

Panel Type	Exposure condition	Panel direction	1/ $\sigma = a + b\rho$, psi a	b	R^2	$Sy\cdot\rho$	1/ $E = a + b\rho$, thousand psi a	b	R^2	$Sy\cdot\rho$
		Ft.								
1/2-inch oriented mixed species	65% RH	8	-4846	223	.642	616	-633.78	34.80	.746	74.95
		4	-2358	124	.735	232	- 67.90	9.68	.536	27.98
	Modified aging	8	-7986	267	.813	525	-125.27	45.88	.931	51.15
		4	-4409	150	.659	318	-750.92	24.15	.355	96.91
	Accelerated aging	8	-6990	237	.749	420	-138.43	48.71	.943	52.40
		4	-2498	107	.640	233	-321.13	14.44	.455	45.80
1/2-inch random mixed species	65% RH	8	-8122	286	.583	519	-870.64	34.37	.633	56.03
		4	- 800	109	.317	542	42.62	11.12	.292	58.89
	Modified aging	8	-8320	270	.543	552	-608.47	27.45	.389	76.86
		4	-5642	199	.505	416	-744.03	27.77	.666	41.48
	Accelerated aging	8	-7024	232	.724	349	-112.67	39.01	.750	54.70
		4	-4152	159	.530	379	-764.09	28.29	.765	39.70
5/8-inch oriented mixed species	65% RH	8	-8157	302	.549	881	-906.85	42.02	.596	111.08
		4	-2712	124	.449	411	-141.28	10.49	.413	37.62
	Modified aging	8	-9505	297	.642	697	-147.26	50.60	.574	137.10
		4	-3451	123	.487	346	-315.06	13.57	.558	32.99
	Accelerated aging	8	-5095	183	.539	565	-105.57	38.66	.520	123.27
		4	-2557	120	.724	249	-157.31	9.29	.286	37.37
5/8-inch random mixed species	65% RH	8	-4606	212	.644	541	-226.39	20.91	.542	66.52
		4	-4329	190	.732	376	-444.06	23.29	.583	64.59
	Modified aging	8	-4169	179	.760	360	-515.52	26.16	.774	50.48
		4	-4034	166	.641	420	-693.51	28.20	.712	59.21
	Accelerated aging	8	-2012	113	.544	373	-337.90	15.48	.269	91.93
		4	-1921	84	.310	320	-419.01	16.49	.291	86.71
1/2-inch random pine	65% RH	8	-5944	263	.721	547	-583.99	31.02	.856	42.45
		4	-1230	122	.611	363	-222.20	18.76	.798	35.21
	Modified aging	8	-2492	164	.621	404	-708.69	33.53	.694	70.25
		4	-3286	171	.725	352	-371.91	22.22	.711	47.46
	Accelerated aging	8	-5037	225	.643	570	-649.18	31.94	.774	58.79
		4	N.S.				-502.53	25.39	.528	64.87
1/2-inch random yellow-poplar	65% RH	8	-3196	217	.729	637	-448.91	30.96	.831	67.16
		4	-7728	310	.804	351	-583.76	30.02	.742	40.92
	Modified aging	8	-3537	221	.561	757	-733.93	38.26	.744	87.18
		4	-5642	255	.634	526	-580.75	30.21	.594	67.85
	Accelerated aging	8	-5140	262	.694	757	-1054.43	48.53	.829	96.04
		4	-4741	230	.568	536	-619.80	31.70	.649	62.24

1/ σ = bending strength; ρ = density based on OD weight and volume at 65% R.H.; E = modulus of elasticity.

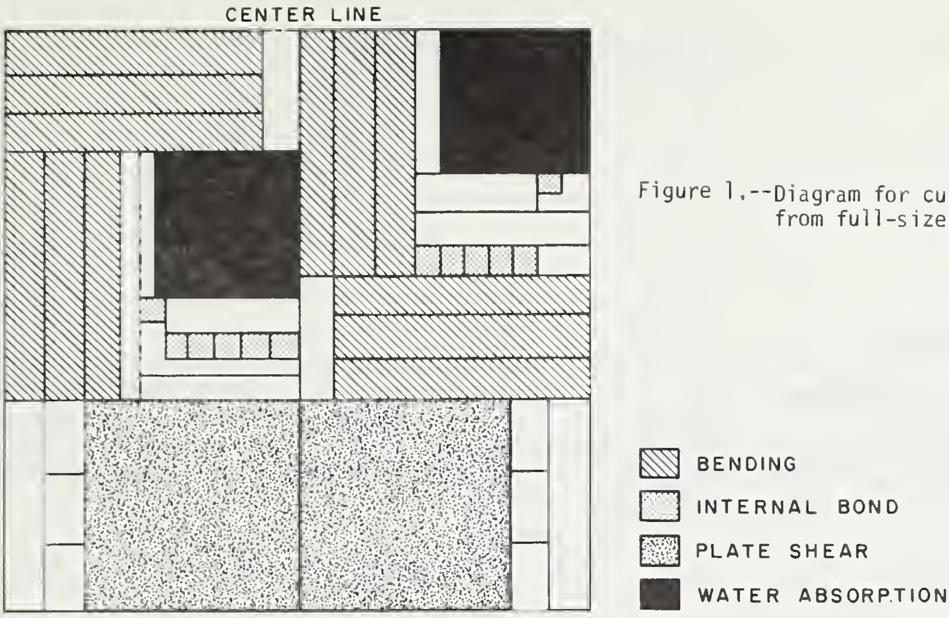

Figure 1.--Diagram for cutting test specimens from full-size panels.

Table 4.-- Calculated bending properties of panels pressed to a density of 46 pounds per cubic foot 1/

Panel type	Panel direction	Exposure condition 65% R.H.	Modified aging	Accelerated agin
		BENDING STRENGTH, psi		
1/2-inch oriented mixed species	8	5412	4296	3912
	4	3346	2491	2424
1/2-inch random mixed species	8	5034	4100	3648
	4	4214	3512	3162
5/8-inch oriented mixed species	8	5735	4157	3323
	4	2992	2207	2963
5/8-inch random mixed species	8	5146	4065	3186
	4	4411	3602	1943
1/2-inch random pine	8	5102	4396	4413
	4	3894	3896	
1/2-inch random yellow-poplar	8	5918	5745	5864
	4	5292	5068	4919
		MODULUS OF ELASTICITY, thousand psi		
1/2-inch oriented mixed species	8	967.02	1985.21	2102.23
	4	377.38	359.98	343.11
1/2-inch random mixed species	8	710.38	1871.17	1681.79
	4	554.14	533.39	537.25
5/8-inch oriented mixed species	8	1026.07	2180.34	1672.79
	4	341.26	309.16	270.03
5/8-inch random mixed species	8	735.47	687.84	374.18
	4	627.28	603.69	339.53
1/2-inch random pine	8	718.85	699.57	692.30
	4	565.72	561.33	563.85
1/2-inch random yellow-poplar	8	851.41	872.99	983.83
	4	677.08	688.07	711.60

1/ Density based on ovendry weight and volume at 65% R.H.

Table 5.--Summary of bending properties

Panel type	65% RH test condition				After modified aging 2/			After accelerated aging 2/		
	Moisture content	Density at test 1/	Bending strength	Modulus of elasticity	Density	Bending strength	Modulus of elasticity	Density	Bending strength	Modulus of elasticity
	%	Pcf	Psi	Thousand psi	%					
8-FOOT DIRECTION										
1/2-in. oriented mixed species	10.86	42.68	4831	866.89	79.9	77.9	87.8	73.8	67.8	81.5
	10.39	47.75	5676	1009.57	79.5	76.9	86.3	72.5	70.1	87.7
1/2-in. random mixed species	10.68	43.13	4314	609.55	80.4	76.8	100.1	73.4	68.8	90.4
	10.66	45.68	4852	701.48	78.2	84.2	91.7	71.3	71.6	91.2
5/8-in. oriented mixed species	10.64	42.82	4655	776.04	77.3	68.0	87.0	72.2	54.1	74.5
	10.33	46.33	5999	1060.48	75.2	72.3	85.0	65.8	55.0	58.0
5/8-in. random mixed species	10.91	39.10	3748	606.05	83.5	75.2	83.9	77.7	61.7	39.6
	10.79	41.69	4026	639.85	81.0	77.7	87.7	74.6	63.6	55.1
	10.58	45.78	5526	736.90	80.3	78.4	95.0	73.1	60.4	41.5
1/2-in. random pine	11.27	39.28	4384	634.45	88.0	91.8	101.5	83.5	83.8	92.7
1/2-in. random yellow-poplar	10.68	39.44	5375	772.10	83.8	96.6	100.3	84.4	91.5	105.0
4-FOOT DIRECTION										
1/2-in. oriented mixed species	10.63	42.67	2909	346.70	79.5	76.9	83.4	73.9	69.3	81.6
	10.43	47.32	3554	388.97	79.2	84.1	102.2	72.4	69.3	89.9
1/2-in. random mixed species	10.63	44.13	4043	530.34	79.7	87.7	92.9	74.4	69.2	86.0
	10.56	46.15	4300	572.71	78.5	79.4	92.5	71.2	67.0	88.2
5/8-in. oriented mixed species	10.76	42.48	2440	302.14	77.0	71.9	86.3	72.2	63.7	75.1
	10.41	45.65	3027	340.04	75.0	76.5	93.0	65.5	64.7	78.9
5/8-in. random mixed species	10.90	39.39	3274	484.17	83.4	76.2	87.6	78.5	64.3	41.5
	10.88	42.04	3611	550.20	80.5	75.7	83.4	74.6	62.8	52.4
	10.66	45.47	4274	574.27	80.4	90.6	112.5	73.4	72.5	55.0
1/2-in. random pine	11.64	39.54	3594	519.48	86.3	101.5	102.3	82.8	127.2	100.2
1/2-in. random yellow-poplar	10.74	39.39	4493	598.40	82.8	100.5	103.9	78.0	92.6	106.8

1/ Density based on OD weight and volume at test.
2/ Average percent retention of the initial values.

Table 6.--Regression equation relating density to internal bond strength of mixed-species panels 1/

Panel types and exposure conditions	IB at 46 pcf	Linear regression, IB = a + bρ, psi			
		a	b	R^2	Sy·ρ
1/2-inch oriented					
50% R.H.	91.8	-170.36	5.70	0.508	13.50
65% R.H.	83.0	-112.03	4.24	.442	16.03
1/2-inch random					
50% R.H.	84.2	-223.55	6.69	.505	7.98
65% R.H.	79.2	- 59.74	3.02	.176	18.77
5/8-inch oriented					
50% R.H.	74.1	-241.05	6.85	.572	14.54
65% R.H.	64.1	-158.10	4.83	.442	16.70
5/8-inch random					
50% R.H.	75.1	-206.43	6.12	.598	12.56
65% R.H.	67.4	- 99.56	3.63	.466	13.03

1/ Density based on OD weight and volume at test.

Table 7.--Percent internal bond failures occurring at designated locations for 1/2-inch panels conditioned at 50 percent R.H.

Board type and density	Failure location 1/			
	F	C	I	L
	----Percent----			
Oriented				
43.22	59.4	31.2	9.4	0
46.75	89.1	3.1	7.8	0
Random				
46.59	56.3	35.9	7.8	6.3
47.92	59.4	23.4	17.2	4.7
Pine				
43.38	28.1	64.1	7.8	4.7
Yellow-poplar				
42.40	26.6	65.6	7.8	6.3

1/ F = face; C = core; I = face-core interface; L = large folded flake occupying at least 30 percent of failure surface.

Table 8.--Summary of internal bond properties for flakeboard panels subjected to various exposures

Panel Types	50% R.H.		65% R.H.		Modified Aging		Accelerated Aging	
	Density 1/	IB	Density 2/	IB	Density 2/	IB	Density 2/	IB
	pcf	psi	pcf	psi	pcf	psi	pcf	psi
1/2-inch oriented	43.22	77.4	42.67	71.1	43.24	12.8	42.46	7.6
mixed species	46.75	95.0	47.54	86.8	47.16	19.5	46.43	11.6
1/2-inch random	46.59	88.7	43.63	72.8	44.21	13.0	42.78	6.6
mixed species	47.92	96.4	45.92	81.6	45.98	14.3	45.36	7.5
5/8-inch oriented	43.72	57.4	42.65	44.0	42.46	5.7	42.43	4.3
mixed species	47.56	85.4	45.99	70.0	46.70	7.6	45.49	5.5
5/8-inch random	42.19	52.6	39.25	41.3	38.99	6.6	38.56	4.9
mixed species	44.61	65.7	42.35	54.4	41.77	7.8	41.20	5.2
	48.42	90.7	45.63	71.1	46.21	10.4	45.50	6.4
1/2-inch random pine	43.38	71.5	39.40	59.7	40.22	24.9	39.54	17.1
1/2-inch random yellow-poplar	42.40	68.3	39.41	65.1	39.62	25.7	38.58	17.1
Avg.	45.16	77.2	43.21	65.3	43.33	13.5	47.57	8.5

1/ Density based on OD weight and volume at 50% R.H.
2/ Density based on OD weight and volume at 65% R.H.

Table 9.--Dimensional stability measured by 24-hour water soak

Panel type and density, pcf	Water absorbtion	Thickness swell		Linear expansion	
				8-foot direction	4-foot direction
	%	%	%/% M.C. 1/	%	
1/2-in. oriented mixed species					
43.63	30.0	20.8	0.338	0.085	0.030
48.30	36.4	17.8	.383	.079	.020
1/2-in. random mixed species					
43.95	21.4	13.2	.454	.055	.090
45.68	21.0	13.2	.445	.062	.101
5/8-in. oriented mixed species					
42.54	36.6	22.7	.463	.193	.143
47.16	27.8	19.0	.351	.190	.129
5/8-in. random mixed species					
38.77	26.7	13.3	.342	.058	.116
42.03	22.5	12.0	.383	.028	.057
47.07	17.1	9.6	.428	.065	.085
1/2-in. random pine					
40.37	27.3	12.9	.331	.020	.053
1/2-in. random yellow-poplar					
39.42	20.5	9.9	.372	.025	.035

1/ The percent thickness swell per percent change in moisture content.

Figure 2.--Diagram of test location for the concentrated load evaluations.

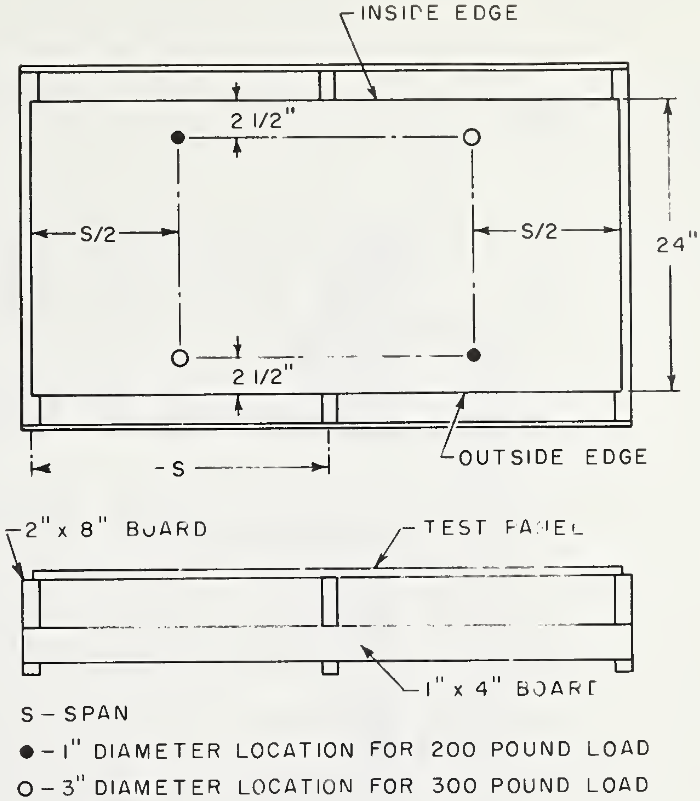

Figure 3.--Diagram of test location for impact test.

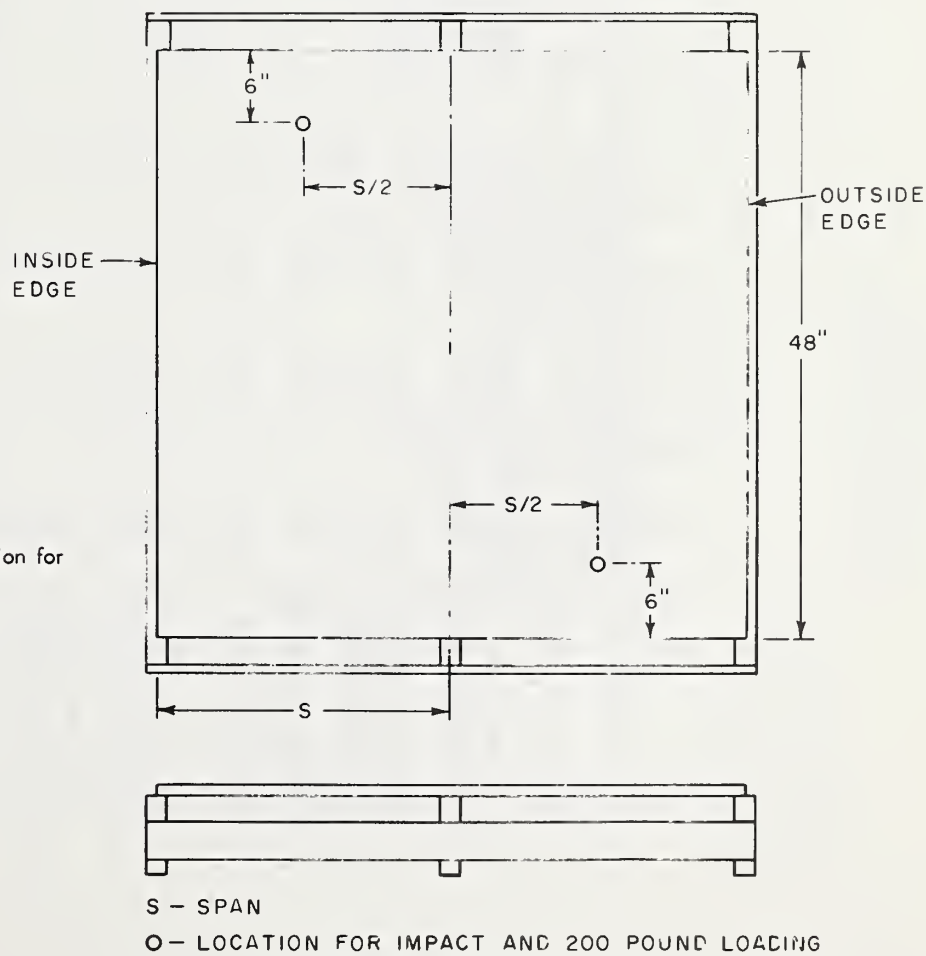

Table 10.--Average deflection, maximum concentrated loads, and average deflection for uniform applied load for mixed species flakeboards

Panel type	Load applied through a 1-inch disk				Load applied through a 3-inch disk				Deflection at 2000-pound uniform load	
	Deflection at 200 pounds		Maximum load		Deflection at 300 pounds		Maximum load			
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	------Inch------		---Pounds---		---Inch------		---Pounds---		----Inch------	
24-INCH SPAN										
1/2-inch oriented	0.311	0.461	442	301	0.452	0.708	573	338	0.189	0.245
1/2-inch random	.313	.452	567	433	.442	.667	672	575	.249	.334
5/8-inch oriented	.184	.269	658	416	.260	.413	769	514	.115	.150
5/8-inch random	.187	.258	764	630	.277	.409	938	740	.146	.188
16-INCH SPAN										
1/2-inch oriented	.133	.185	598	364	.188	.275	748	494	.039	.043
1/2-inch random	.126	.198	678	509	.188	.292	850	612	.040	.062
5/8-inch oriented	.073	.122	817	510	.105	.177	1015	600	.032	.026
5/8-inch random	.076	.114	905	700	.105	.177	1173	861	.027	.032

Table 11.--Flakeboard deflection and load carrying capacity for concentrated applied loads and deflection with a 2,000-pound distributed load.

Panel type and density, pcf	Load applied through a 1-inch disk: Deflection at 200 pounds, Dry		Wet		Maximum load, Dry		Wet		Load applied through a 3-inch disk: Deflection at 300 pounds, Dry		Wet		Maximum load, Dry		Wet		Deflection at 2000-pound distribution load		Moisture content at test	
	I1/	01/	I	0	I	0	I	0	I	0	I	0	I	0	I	0	Dry	Wet	Dry	Wet
	------Inches------				-----Pounds-----				------Inches------				-------Pounds-------				----Inches----		---Percent---	
24-INCH SPAN																				
1/2-inch oriented mixed species																				
44.0	0.287	0.322	0.422	0.530	515	386	325	314	0.427	0.452	0.621	0.725 3/	650	473	364	302	0.183	0.248 3/	6.5	84.2
48.1	.325	.310	.398	.494	455	480	289	276	.457	.470	.673	.690	625	543	353	374	.195	.242	6.4	69.5
1/2-inch random mixed																				
46.6	.337	.302	.468	.485	504	575	405	423	.483	.456	.757	.644	620	611	488	543	.263	.356	5.6	54.1
47.8	.317	.296	.435	.420	545	644	474	429	.412	.415	.660	.607	728	729	616	653	.235	.311	5.7	33.8
5/8-inch oriented mixed species																				
43.3	.187	.182	.258	.379	665	543	409	354	.294	.261	.392	.611	744	648	496	456	.122	.188	6.4	91.6
47.0	.167	.198	.217	.222	788	636	452	450	.232	.251	.290	.358	928	754	620	484	.108	.111	6.4	77.6
5/8-inch random mixed species																				
42.1	.212	.199	.309	.278	690	723	466	513	.285	.289	.473	.423	753	848	603	563	.153	.198	5.9	54.5
43.3	.191	.187	.284	.269	659	776	435	531	.302	.283	.473	.402	813	916	559	608	.156	.199	6.2	53.8
48.2 2/	.204	.167	.248	.228	800	818	650	903	.273	.248	.370	.390	955	1065	918	875	.136	.176	5.9	27.1
1/2-inch random pine																				
43.2	.361	.285	.484	.456	445	578	378	380	.528	.414	.718	.634	590	675	487	535	.263	.342	6.0	68.4
1/2-inch random yellow-poplar																				
40.8	.292	.273	.357	.378	611	630	520	495	.445	.399	.568	.564	691	781	594	639	.223	.262	5.9	30.3
16-INCH SPAN																				
1/2-inch oriented mixed species																				
44.1	.118	.152	.175	.180	608	564	379	359	.171	.214	.248	.293	854	650	473	473	.037	.043	6.9	80.0
48.7	.134	.127	.157	.227	640	580	423	295	.177	.188	.241	.314	785	704	574	453	.040	.043	6.4	65.0
1/2-inch random mixed species																				
45.3	.123	.134	.222	.207	696	648	491	458	.177	.189	.314	.301	808	876	489	543	.038	.065	6.7	49.5
46.7	.119	.128	.182	.178	738	630	521	564	.178	.194	.293	.259	871	843	728	688	.042	.058	6.9	43.7
5/8-inch oriented mixed species																				
43.3	.068	.076	.112	.135	825	611	498	438	.098	.120	.159	.222	1006	764	497	456	.032	.031	6.5	85.1
48.2	.073	.076	.102	.140	925	906	594	510	.097	.104	.136	.189	1214	1075	771	676	.033	.020	6.5	75.7
5/8-inch random mixed species																				
41.0	.106	.089	.158	.135	725	778	554	599	.117	.122	.212	.171	1003	801	614	765	.021	.037	6.8	59.5
43.9	.092	.084	.126	.129	759	825	627	614	.117	.110	.196	.174	1148	1109	700	845	.036	.029	6.5	54.7
44.3	.059	.068	.099	.101	1103	933	845	715	.096	.097	.161	.176	1265	1168	868	1030	.017	.035	6.8	40.7
1/2-inch random pine																				
42.0	.105	.150	.202	.190	821	500	474	467	.159	.204	.320	.291	985	734	563	581	.046	.062	6.9	73.8
1/2-inch random yellow-poplar																				
40.8	.104	.122	.159	.154	858	630	501	681	.161	.182	.247	.211	1016	889	724	915	.041	.051	6.3	25.9

1/ I = inside edge; 0 = outside edge.
2/ Average of two panels instead of four panels.
3/ The average of three panels.

Table 12. Average impact test and 200-pound concentrated load evaluation on flakeboards and plywood panels. The ratio of flakeboard to plywood is inside the parentheses.

Panel type and density, pcf	Moisture content at test		Maximum drop height		Deflection at maximum drop		Deflection with 200-pound concentrated force			
							Initial		Final	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
	------%-------		------Inches------							
24-INCH SPAN										
1/2-inch oriented mixed species	6.94 (1.00)	74.36 (1.85)	35 (.55)	31 (.52)	0.195 (.90)	0.196 (.91)	0.207 (.96)	0.258 (.94)	0.339 (1.06)	0.441 (1.28)
1/2-inch random mixed species	5.78 (.83)	32.57 (.81)	51 (.80)	56 (.93)	.220 (1.01)	.220 (1.02)	.210 (.98)	.252 (.92)	.326 (1.02)	.368 (1.07)
1/2-inch pine plywood	6.94	40.12	64	60	.217	.215	.215	.274	.321	.344
1/2-inch random pine	6.65 (.96)	61.94 (1.54)	52 (.81)	55 (.92)	.227 (1.05)	.215 (1.00)	.193 (.90)	.240 (.88)	.332 (1.03)	.384 (1.12)
1/2-inch random yellow-poplar	5.49 (.79)	25.41 (.63)	60 (.94)	72 (1.20)	.224 (1.03)	.257 (1.20)	.180 (.84)	.208 (.75)	.311 (.97)	.345 (1.00)
16-INCH SPAN										
5/8-inch oriented mixed species	6.96 (1.08)	88.15 (2.08)	64 (.91)	56 (.62)	.171 (1.36)	.179 (1.16)	.057 (.91)	.071 (.76)	.106 (.91)	.257 (1.65)
5/8-inch random mixed species	6.08 (.94)	28.95 (.68)	58 (.83)	77 (.86)	.188 (1.49)	.187 (1.21)	.055 (.87)	.067 (.71)	.085 (.73)	.112 (.72)
5/8-inch pine plywood	6.44	42.37	70	90	.126	.154	.063	.094	.117	.156

Table 13. Flakeboard and plywood impact properties and deflection resulting from a 200-pound concentrated load applied before and after impact evaluation

Panel type and density, pcf	Maximum drop height				Deflection at maximum drop				Deflection with 200-pound concentrated force							
	Dry		Wet		Dry		Wet		Initial				Final			
									Dry		Wet		Dry		Wet	
	I[1]	O[1]	I	O	I	O	I	O	I	O	I	O	I	O	I	O
					Inches											
24-INCH SPAN																
1/2-inch oriented mixed species																
44.0	32	33	27	26	0.194	0.187	0.191	0.199	0.206	0.202	0.250	0.279	0.362	0.338	0.479	0.475
46.9	42	32	34	36	.219	.178	.192	.200	.205	.214	.250	.250	.330	.326	.382	.427
1/2-inch random mixed species																
43.6	45	50	48	64	.225	.219	.212	.250	.212	.212	.268	.250	.342	.336	.391	.383
45.4	55	53	59	54	.219	.216	.223	.195	.214	.199	.240	.247	.319	.303	.336	.360
1/2-inch pine plywood																
34.1	64	64	68	51	.216	.217	.235	.195	.229	.200	.253	.294	.331	.310	.315	.373
1/2-incn random pine																
41.3	49	55	53	57	.214	.240	.203	.227	.194	.191	.246	.233	.328	.335	.401	.367
1/2-inch random yellow-poplar																
40.6	59	61	62	81	.225	.223	.249	.265	.187	.173	.210	.206	.322	.299	.358	.331
16-INCH SPAN																
5/8-inch oriented mixed species																
41.9	59	57	51	55	.150	.219	.167	.218	.060	.058	.072	.075	.114	.156	.240	.306
46.1	69	71	58	61	.183	.131	.158	.172	.054	.057	.063	.073	.077	.077	.196	.286
5/8-inch random mixed species																
42.2	51	58	73	78	.173	.188	.188	.169	.058	.056	.070	.070	.085	.080	.110	.135
44.1	57	66	77	78	.183	.208	.192	.200	.054	.051	.066	.061	.072	.101	.099	.100
5/8-inch pine plywood																
33.3	56	84	82	97	.114	.137	.141	.167	.066	.060	.099	.088	.109	.124	.161	.151

[1] I = inside edge; O = outside edge.

MANUFACTURE AND PERFORMANCE OF FULL-SIZE STRUCTURAL FLAKEBOARDS FROM DOUGLAS-FIR FOREST RESIDUES

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Abstract

The Forest Products Laboratory manufactured and assessed the performance of 4- by 8-foot structural flakeboard panels from Douglas-fir forest residues after target performance goals were developed. The 42 lb/cu.ft., three-layer boards were 1/2 inch thick with high quality disk cut flakes for the faces and lower quality flakes processed through a ring flaker in the core. More than 200 panels were produced. Basic mechanical and physical properties were evaluated, as well as durability and performance under concentrated and impact loading, racking strength of wall and floor sections, and fire exposures. Bending strength and stiffness were both below the target goals. Most other goals were met; including those for shear and nailholding properties, internal bond, and hardness. Panels used as wall sheathing exceeded specified acceptance standards for full-size walls. Under concentrated load, panels met maximum load and deflection recommendations of the Uniform Building Code for roofs and floors. Under fire exposure, the panels had a class B flame spread rating and exceeded the fire endurance requirement for exterior walls of one- and two-family dwellings.

Introduction

Forest residues which have been, at times, estimated to amount to 9.6 billion cubic feet annually, can be grouped into three primary categories: timber damaged by insects, disease and fire; logging residues; and precommercial thinning. Logging residues alone offer more than three times the volume of raw material used annually in the plywood industry (7).[2]

To improve the utilization of these residues, the U.S. Forest Service set up a national research program to develop a structural flakeboard that could be manufactured from this presently unused material (8).

The goals of the research at the Forest Products Laboratory (FPL) were to provide the technology and procedures that would enable industry to produce a panel product made primarily from softwood logging residues that would be fully adequate as an exterior-grade construction material. This paper is a summary of the following reports prepared as part of the Forest Service National Structural Flakeboard Program.

1. Manufacture of full-size structural flakeboards - William F. Lehmann.
2. Small specimen properties of full-size structural flakeboards from Douglas-fir forest residues - Matti J. Hyvarinen and Michael J. Superfesky.
3. Dimensional stability of FPL structural flakeboard - William F. Lehmann.
4. Concentrated and impact load testing of FPL's structural flakeboard - J. Dobbin McNatt and Michael J. Superfesky.
5. Racking strength of panels sheathed with Forest Service structural flakeboard - William J. McCutcheon.
6. Fire performance of structural flakeboard from forest residues - Carlton A. Holmes, Herbert W. Eichner, John J. Brenden, and Robert H. White.

Manufacture of Full-Size Panels

The raw materials used were primarily Douglas-fir forest residues gathered from logging operations on the western slopes of the Cascade Mountains in Washington State and shipped to the Forest Products Laboratory, Madison, Wisconsin. These were primarily broken logs of diameters varying from about 5 to 24 inches and containing variable amounts of decay.

The materials were segregated for conversion into flakes such that they contained approximately 75 percent sound wood larger than 6 inch diameter, 12-1/2 percent wood with decay, 6-1/4 percent sound wood less than 6 inches in diameter, and 6-1/4 percent bark. The overall flakeboard manufacturing process is outlined in Figure 1.

The better residues were selected for face flake material and debarked. Face flake material was then cut into billets 2 inches along the grain and 1 inch in width. These billets then were flaked in the laboratory disk flaker.

The remaining residues were cut into 12 to 13 inch lengths. These lengths were fed into a drum chipper constructed to produce chips of 1/4 to 3/8 inch thickness and 2 to 2-1/2 inches in length. The large chips were further processed

[1] Symposium paper prepared from six reports for publication written by: W.F. Lehmann (2 reports); M.J. Hyvarinen and M.J. Superfesky; J.D. McNatt and M.J. Superfesky; W.J. McCutcheon; and C.A. Holmes, et al., and listed in the Introduction.

[2] Underlined numbers in parentheses refer to literature cited at the end of this paper.

through a ring flaker. The following factors remained constant during manufacture:

- Raw material--Douglas-fir forest residues
- Panel size--0.5 x 50 x 108 inches
- Panel density--43 pcf (target), based on oven dry weight and nominal volume
- Face flakes--0.02 x 1 x 2 inch disk flakes
- Core flakes--0.05 x 2 x random width ring flakes
- Face: core flake ratio--30:70 percent by weight of flakes
- Resin binder and amount--liquid phenolic resin, 5 percent resin solids based on ovendry weight of flakes
- Wax type and amount--wax emulsion, 1 percent wax solids based on ovendry weight of flakes
- Mat moisture content--10 ± 1 percent
- Press cycle--10 minutes at 305°F, press closed to stops in 1 minute
- Trimmed panel size--48 x 96 inches.

Phenolic resin and wax were blended together and applied to the flakes by air spray at 3 to 4 oz/min/spray gun at 40 psi atomizing air pressure.

Immediately following blending, the flakes were formed into the three-layered, 50 x 108 inch mats using a simple mechanical forming device. Because of the press size, 4 x 20 feet, two mats were required for each press load. The formed mats were placed end-to-end and loaded into the 54 x 250 inch, steam-heated, 3,000 ton capacity hot-press. The press was immediately closed and the pressure cycle shown in Figure 2 was followed. Press temperature was 350°F. The pressure-time step sequence shown was used to approximate as closely as possible the press cycle normally used with small-size laboratory panels. The short delay at the beginning allowed the surface flakes to heat prior to the rapid application of high pressure. This then provided a high density surface to promote high stiffness. The step pressure decreases used after reaching the desired thickness provided a means of maintaining thickness while reducing the transfer of pressure to the stop bars.

In total, 216 panels were produced in this study, of which the final 151 panels were randomly assigned to the various strength, fire, stability, and durability tests. The initial 65 panels were produced to develop the procedural sequences needed to manufacture efficiently a consistent and high-quality panel product.

Basic Engineering Properties From Small Specimen Tests

Specimen Preparation and Testing

Basic engineering properties of the full-size Douglas-fir structural flakeboards were determined using small-specimen tests to compare their quality with target performance goals established early in the Forest Service Structural Flakeboard program. Properties evaluated included bending, tension, compression, internal bond, shear, nail holding, hardness and impact. Tests were conducted on specimens conditioned to EMC at 65 percent relative humidity. Some tests were also conducted after 24-hour water-soak and after accelerated aging. Overall density and density gradient were also determined. Tests were performed according to applicable ASTM Standards (4,5). Sixty-five of the final 151 panels were randomly selected for small specimen tests and the small specimens were cut both parallel to and perpendicular to the panel length from randomly selected areas of each of the 65 panels.

Results

The static bending and nail-holding properties are summarized in Tables 1 and 2; the hardness, impact resistance (falling ball tests), internal bond strength, strength in tension and compression parallel to surfaces, and shear in Table 3.

Equilibrium moisture content at 65 percent relative humidity averaged 8.0 percent, and density averaged 41.6 lb/cu ft as determined from static bending specimens. Density gradient through the panel thickness is shown in Figure 3, as determined from selected specimens.

Both modulus of rupture (MOR) and modulus of elasticity (MOE) in bending indicated that the Forest Service structural flakeboard had some directional properties despite the random flake orientation. Averages along and across the forming direction were 4,700 and 4,260 psi in MOR and 714,000 and 673,000 psi in MOE, respectively.

Forest Service Flakeboard and Target Values

The target values (Table 4) were met or exceeded for modulus of rupture after aging (the actual value was 84 percent of the dry value vs. the target value of at least 50 percent), lateral nail-holding dry (503 vs. 300 pounds) and wet (332 vs. 150 pounds), nail-head pull-through (460 vs. 250 pounds), near minimum[3] Janka ball hardness (765 vs. 500 pounds), internal bond strength dry (111 vs. 70 psi), edgewise shear strength (1,630 vs. 1,000 psi), interlaminar shear strength (395 vs. 250 psi), direct nail withdrawal resistance dry (73 vs. 40 pounds) and wet (58 vs. 25 pounds).

However, the target values were not met for the density range, from near minimum to near maximum[4] (36.9 to 46.2 pcf actual vs. 37.0 to 43.0 target), near minimum modulus of rupture in static bending (3,030 vs. 4,500 psi), modulus of elasticity in static bending (693,000 vs. 800,000 psi), near maximum Janka ball hardness (1,481 vs. 1,200 pounds), and internal bond strength after aging (43 vs. 50 percent).

Cyclic Humidity Exposure

Specimen Preparation

Randomly-selected 2- by 4-foot sections of 65 full-size panels were each cut into twelve

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[3] 5 percent lower exclusion limit.

[4] 5 percent upper exclusion limit.

3- by 12-inch specimens for determination of dimensional stability and strength retention after cyclic moisture exposure.

The 780 - 3 by 12 inch specimens were randomly assigned to three groups of 260 specimens with the restriction that each group received an equal number of specimens from each panel and each major panel dimension.

The three groups of 260 specimens then were subjected to the following exposures and determinations of dimensional stability (water absorption (WA), thickness swelling (TS), and linear expansion (LE)) and related properties:

1. Ovendry exposure. 260 specimens were ovendried at 216 ± 4°F and weighed and measured.
2. Relative humidity (RH) exposure. 30 to 50 to 90 percent RH followed by 12 cycles of 30 to 90 percent RH. Specimens were placed in conditioning rooms at 80°F and appropriate humidity and maintained for 30 days during each step of the initial 30 to 50 to 90 percent RH exposure. Succeeding cycles of 90 to 30 to 90 percent RH were in 21-day increments at each step of the cycle. Specimens were weighed and measured at cycles 1, 3, 6, and 12; then 65 specimens representing both major panel dimensions were removed, dried at 120°F for 3 days and tested without further conditioning for retention of bending stiffness, strength and internal bond strength. Testing procedures conformed to ASTM D1037-72a[4] and bending property calculations were based on initial specimen thickness.

3a. Watersoak exposures. 24-hour watersoak (WS) in 70°F water followed by 24 cycles of 1-hour soaking in 150°F water and 22 hours of drying at 160°F. Specimens were weighed and measured at cycles 1, 3, 6, 12, and 24; after each cyclic series 26 specimens were removed, dried for 3 days at 120°F and tested without further conditioning for retention of strength. All watersoak tests were performed with specimens in a horizontal position under 1 inch of water.

3b. Ovendry-vacuum-pressure-soak exposures. 24 hour WS in 70°F water followed by 24 cycles consisting of 30 minutes submerged in 70°F water under a vacuum of 26 inches of Hg, 60 minutes at 50 psi pressure and 22 hours drying at 160°F. Specimens were weighed and measured at cycles 1, 3, 6, 12, and 24; after each cyclic series 26 specimens were removed, dried for 3 days at 120°F and tested without further conditioning for retention of strength.

Results

Results of these evaluations are illustrated graphically in Figures 4 to 9 and indicate that structural flakeboards as prepared in this study can undergo prolonged and reasonable exposures to cyclic wet and dry conditions with minimal loss of strength and bond integrity and with reasonable changes in dimensions. If exposures are limited to cyclic humidity conditions, there appears to be little, if any, loss in up to 12 cycles of exposure, indicating good product durability in long-term exposures to either liquid or water vapor.

Concentrated and Impact Load Testing

Specimen Preparation

Concentrated load tests were conducted on 65 randomly-selected 2 by 4 foot panels; 55 were tested "dry" after conditioning at 65 percent relative humidity, and 10 were tested "wet" after soaking in water for 24 hours. Tests were also conducted on 20 randomly-selected 4 by 4 foot panels nailed to joists after conditioning at 65 percent relative humidity. The 2 by 4 foot panels were simply supported along the 4-foot-long sides by 4-inch-diameter steel pipes spaced 16 inches on center and resting on glued-laminated beams. A concentrated load was applied at the center of each panel, first by a 4-inch-diameter disk up to a maximum of 300 pounds; and then by a 1-inch-diameter rod up to failure. Deflection was measured relative to the supports, under the load point by a LVDT. The 4 by 4 foot flakeboard panels were nailed to 2 by 4 inch joists spaced 16 inches on center using 8-penny common nails spaced 6 inches apart. The 2 by 4 joists rested on glued-laminated beams. The concentrated load was applied to the center of one of the end spans, first by a 3-inch-diameter disk up to a maximum of 300 pounds; and then by a 1-inch-diameter rod up to failure.

For all concentrated load tests, load deflection ratios were calculated from the slope of the initial portion of the load deflection curves. Also recorded was the load at failure when loading with the 1-inch-diameter rod.

Impact load tests were conducted on 20 randomly selected 2 by 4 foot panels, 10 each "wet" and "dry" as defined above. Impact tests were also conducted on the other end span of the 20 "dry" 4 by 4 foot panels subjected to concentrated loads. An additional 5 "wet" 4 by 4 foot panels were tested. The 60-pound leather sandbag described in ASTM E72 (2) was used in all impact tests. The 2 by 4 foot panels were simply supported along the 4-foot-long edges on the rounded tip edge of 2 by 8 inch members spaced 16 inches on center. The supports were bolted to glued-laminated girders to hold them in position during impact. The sandbag was dropped on the center of the panel.

The 4 by 4 foot panels nailed to 2 by 4 inch joists also were bolted to the glued-laminated beams to hold the panel in position during impact. The sandbag was dropped on the center of the end span of the "dry" panels not subjected to concentrated load testing and on the center of each of the two end spans of the "wet" panels.

The procedure for dropping the sandbag and measuring deflection was the same for both size panels. The bag was initially dropped from a height of 6 inches, and the height was successively increased in increments of 6 inches until failure occurred. Failure was considered to have occurred when the residual deflection exceeded 1/8 inch. After initial impact on each drop the sandbag was restrained with a rope and pulley to prevent additional impacts from the same drop. Prior to each test the sandbag was rolled on the floor to loosen the sand since packing of the sand would change the energy

absorption behavior of the bag.

Deflection of the panel during impact and residual deflection after each impact was measured by an LVDT attached to the underside of the panel directly under the load point by means of a ball and socket arrangement. Time-deflection data were recorded and stored in a digital storage oscilloscope. Time deflection curves for each drop were drawn by means of a digital-to-analog converter whereby the oscilloscope memory was played back to an X-Y recorder at a slower sweep rate. Peak dynamic deflection, time to peak deflection, and residual deflection were read off the oscilloscope.

Results

Results of concentrated and impact load tests are given in Tables 5 and 6 and can be summarized as follows:

Concentrated Load

1. Load-deflection ratios were increased by increasing the area under load from 1 inch in diameter to 4 inches in diameter.
2. Load-deflection ratios decreased when the flakeboard panels were soaked in water for 24 hours. However, load at failure changed little.
3. Load-deflection ratios were about the same for the 2 by 4 foot simply-supported panels and the 4 by 4 foot panels nailed to joists when the 4-inch-diameter loading disk was used. However, the ratios were somewhat larger for the 4-foot-square panels than for the smaller panels when the 1-inch-diameter rod was used.
4. Performance of the panels exceeded the maximum load and allowable deflection values recommended by the Uniform Building Code for floor and roof sheathing (9).

Impact Load

1. Neither height of drop at failure or time to maximum deflection were affected by soaking the panels in water for 24 hours.
2. Height of drop at failure was greater and time to maximum deflection was less for the 4 by 4 foot panels nailed to joists 16 inches on center than for the 2 by 4 foot panels simply-supported over a 16-inch span.
3. The sand bag produced a flexure failure along the length of the 2 by 4 foot panels, but produced a puncture failure in the 4 by 4 foot panels.

Racking Strength of Walls and Floors

Seven full-size 8 by 8 foot walls were sheathed with FPL structural flakeboard and tested in racking according to ASTM E72 (2). Four were tested dry and three were tested after being subjected to wetting cycles specified in ASTM E72. Dry racking strength averaged just over 6,200 pounds and wet strength averaged just under 5,900 pounds. Both these values are well above the generally accepted standards of 5,200 pounds dry and 4,000 pounds wet (6).

Fire Performance

Flame spread properties of the FPL structural flakeboard were determined by the 25-foot tunnel furnace test of ASTM E84-70 (3).

The flame spread clsssification (FSC) values obtained in the two tests with the FPL structural flakeboard in the 25-foot rating furnace were 70 and 72 with an average of 71. This meets the acceptance flame spread criteria under building codes for class B material--75 or under flame spread. This classification will permit its use in many building occupancies, and applications where flame spread of building materials is limited; for example, in exitways and corridors.

The FPL flakeboard was also tested in load-bearing wood-frame walls for fire endurance in the Forest Products Laboratory large vertical furnace. Two tests were conducted according to ASTM Standard E119-73 (1) except the panel height was limited to 8 feet and the applied load was 1,250 pounds per linear foot (the computed maximum loading for the first floor wall of a two-story house of average size). This was 27 percent higher than design load based on allowable compression perpendicular to grain stress at the plate and only 2 percent less than design load based on allowable compression parallel-to-grain stress in the studs. For one wall the interior facing was 3/8-inch gypsum wallboard panels which were vertically applied to the frame with 1-inch-long, fourpenny gypsum wallboard nails, spaced 8 inches on center. All joints were taped and covered with joint compound and nailheads were indented and covered with joint compound. One coat of latex paint was applied. For the second wall, the interior facing was the 1/2-inch-thick flakeboard panels vertically attached to the framing with sixpenny nails spaced 8 inches on center at edges and 12 inches at intermediate locations.

For the wall with gypsum wallboard interior facing, burnthrough occurred after 33 minutes, 20 seconds. The wall with flakeboard interior facing burned through after 31 minutes, 35 seconds. Both are in excess of the 20 minutes required for exterior walls in the Minimum Property Standards for Single- and Double-Family Dwellings of the Department of Housing and Urban Development (10). Details on these and other fire performance tests conducted on the FPL flakeboard are given in paper No. 6 listed in the introduction.

Summary

The Forest Products Laboratory produced more than 200 full-size (4- by 8-foot) three-layer structural flakeboards from Douglas-fir forest residues and evaluated their potential as an exterior-grade construction material. Results of tests were compared with target goals for certain basic properties which had been developed earlier. Target goals were not met for some basic properties (bending strength and stiffness and retention of internal bond strength after accelerated aging, for instance), but were surpassed for other properties (nailholding, shear, hardness).

The following results from performance-type testing help indicate that the panels would be acceptable as an exterior sheathing product:

1. Under concentrated load, the panels surpassed the maximum load and allowable deflection values recommended by the Uniform Building Code for floor and roof sheathing.

2. Racking strength of full-size wall sheathed with the panels exceeded the accepted FHA standard.

3. Under fire exposure, panels met the acceptance flame spread criteria under building codes for class B material. Fire endurance for load-bearing walls sheathed with the panels exceeded the 20 minutes required for exterior walls in the HUD minimum Property Standards for Single- and Double-Family Dwellings.

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Table 1.--Static bending properties Forest Service structural flakeboard

Property	Mean	Standard deviation	Minimum	Maximum	Coefficient of variation	Sample size
					Pct	
Original thickness, in.						
Specimens for dry series1/	0.514	0.016	0.469	0.563	3	390
Original density, lb/ft^3						
Specimens for dry series	41.6	2.81	33.8	51.2	7	390
Moisture content, pct						
Dry (65 pct RH)	8.0	.7	6.0	9.6	9	390
Wet (24 h soak)	25.5	4.0	16.1	42.5	16	130
Aged (65 pct RH)	9.6	.3	8.9	11.1	3	130
Modulus of rupture, lb/in.^{2}						
Dry ||2/	4,700	942	2,360	7,180	20	195
⊥3/	4,260	759	2,650	6,310	18	195
All	4,480	881	2,360	7,180	20	390
Wet ||	3,620	785	2,060	6,490	22	65
⊥	3,300	637	1,930	5,100	19	65
All	3,460	730	1,930	6,490	21	130
Aged ||	3,860	686	1,670	5,070	18	65
⊥	3,540	691	2,250	5,460	20	65
All	3,700	705	1,670	5,460	19	130
Modulus of elasticity, 1,000 lb/in.^{2}						
Dry ||	714	117	404	1,057	16	195
⊥	673	96	445	972	14	195
All	693	109	404	1,057	16	390
Wet ||	548	105	378	976	19	65
⊥	493	93	326	788	19	65
All	521	102	326	976	20	130
Aged ||	676	87	386	827	13	65
⊥	614	91	440	858	15	65
All	645	94	386	858	15	130

1/ Dry specimens: Conditioned to EMC at 73° F, 65 pct RH.

2/ ||: Specimen length parallel to 8-foot dimension of panel.

3/ ⊥: Specimen length parallel to 4-foot dimension of panel.

Table 2.--Nail-holding properties[1/]

Property and condition	Mean	Standard deviation	Coefficient of variation	Minimum value	Maximum value
	Lb	Lb	Pct	Lb	Lb
Lateral nail resistance:[2/]					
Dry[3/]	503	82	16	209	710
Wet[4/]	332	77	23	190	615
Aged[5/]	381	88	23	195	650
Nail-head pull-through					
Dry	460	88	19	280	790
Wet	410	88	21	225	640
Aged	374	94	25	188	688
Direct nail withdrawal					
Dry	73	19	26	35	124
Wet	58	19	33	12	128

1/ Sixpenny common wire nail used. All values are averages of 130 specimens.

2/ 1/2-inch edge distance used.

3/ Dry: Conditioned to EMC at 73° F and 65 pct RH.

4/ Wet: Soaked in water 24 hours and tested wet.

5/ Aged: Subjected to 6 cycles of accelerated aging.

Table 3.--Hardness, impact resistance, internal bond strength, strength in tension and compression parallel to surface, shear properties and sag modulus of elasticity of Forest Service structural flakeboard

Property	Mean	Standard deviation	Minimum	Maximum	Coefficient of variation	Sample size
					Pct	
Janka ball hardness, lb.	1,122	215	680	1,640	19	65
Falling ball impact, failure height, in.	65	6.5	48	74+	10	65
Internal bond strength, lb/in.^{2}						
Dry	111	28	59	176	25	130
Aged	49	20	10	106	41	130
Tension parallel to surface, Modulus of elasticity, 1,000 lb/in.^{2} 1/						
$\parallel$	615	178	126	999	29	111
$\perp$	539	175	70	980	32	115
All	577	180	70	999	31	226
Tension strength, lb/in.^{2} 1/						
$\parallel$	2,024	396	1,260	3,290	20	129
$\perp$	1,723	309	1,090	2,630	18	130
All	1,873	385	1,090	3,290	21	259
Compression parallel to surface Modulus of elasticity, 1,000 lb/in.^{2}						
$\parallel$	603	114	333	885	19	130
$\perp$	455	89	290	702	20	130
All	529	126	290	885	24	260
Compressive strength						
$\parallel$	2,690	459	1,620	4,040	17	130
$\perp$	2,270	377	1,450	3,340	17	130
All	2,480	469	1,450	4,040	19	260
Shear properties						
Edgewise shear strength, lb/in.^{2}	1,630	251	1,210	2,390	15	65
Interlaminar shear strength, lb/in.^{2}	395	73	244	641	18	65
Interlaminar shear modulus, 1,000 lb/in.^{2}	44	7	31	68	16	65
Plate shear modulus, 1,000 lb/in.^{2}	287	30	226	362	10	65

1/ 19 $\parallel$ and 15 $\perp$ MOE values omitted from average due to malfunction of deformation gage. One tensile strength value omitted because specimen failed in grips.

Table 4.--Actual versus target goals for properties of Douglas-fir structural flakeboard

Property	Target	Units	Actual
Density			
Near minimum 1/	37	lb/ft^3	36.9
Near maximum 2/	43	--	46.2
Modulus of rupture			
Near minimum 1/			
Dry (65 pct RH)	4,500	$lb/in.^2$	3,030
After accelerated aging 3/	2,250		2,530
Modulus of elasticity			
Mean	800,000	$lb/in.^2$	693,000
Hardness 4/			
Near minimum 1/	500	lb	765
Near maximum 2/	1,200	lb	1,480
Internal bond			
Mean			
Dry	70	$lb/in.^2$	113
After accelerated aging 3/	50	pct of dry	43
Edgewise shear strength			
Mean (dry)	1,000	$lb/in.^2$	1,630
Interlaminar shear strength			
Mean (dry)	250	$lb/in.^2$	395
Lateral nail resistance 5/, 6/			
Mean			
Dry	300	lb	503
After accelerated aging 3/	150	lb	332
Nailhead pullthrough 5/			
Mean			
Dry	250	--	460
After accelerated aging	125	--	374
Direct nail withdrawal 5/			
Mean			
Dry	40	--	73
After 24-h soaking	25	--	58
After accelerated aging	20	--	--

1/ 5 pct lower exclusion limit.
2/ 5 pct upper exclusion limit.
3/ ASTM D1037-72a, Sec. 118-122.
4/ Janka Ball.
5/ 6-penny common wire nail.
6/ 1/2-inch edge distance.

Table 5.--Concentrated load behavior of FPL structural flakeboard.

Panel Type	No. of Tests	Panel Density[1]	Load-Deflection Ratio: 4-inch Dia. disk[2]	Load-Deflection Ratio: 1-inch Dia. Rod.	Load at Failure: 1-inch Dia. Rod.
		lb/cu.ft.	lb/in.	lb/in.	lb
2 x 4 foot, dry[3]	55				
Average		44.8	2,693	2,168	789
Range		38.5-50.1	2,083-3,333	1,705-2,752	520-975
2 x 4 foot, wet[4]	10				
Average		44.6	2,084	1,712	781
Range		40.6-47.1	1,648-2,381	1,339-1,935	645-935
4 x 4 foot, dry[3]	20				
Average		44.3	2,621	2,387	826
Range		41.6-46.3	2,069-3,030	1,863-2,703	665-960

[1] Density is based on weight and dimensions at 65 percent relative humidity.

[2] 3-inch-diameter disk for 4 by 4 foot panels.

[3] "Dry" panels were as conditioned to EMC at 65 percent relative humidity.

[4] "Wet" panels were soaked in water for 24 hours.

Table 6.--Results of impact load testing of FPL structural flakeboard.

Panel Type	Number of Tests	Panel Density	Height of Drop at Failure	Time to Maximum Deflection
		lb/cu.ft.	Inches	Milliseconds
2 x 4 foot, dry[2]	10			
Average		44.8	27	18
Range		38.6-48.5	24-30	16-20
2 x 4 foot, wet[3]	10			
Average		44.8	29	18
Range		40.4-49.0	24-36	16-20
4 x 4 foot, dry[2]	20			
Average		44.3	36	14
Range		41.6-46.3	30-42	13-16
4 x 4 foot, wet[3]	10[4]			
Average		45.1	38	15
Range		43.0-47.2	30-42	14-16

[1] Density is based on weight and dimensions at 65 percent relative humidity.

[2] "Dry" specimens were conditioned at 65 percent relative humidity.

[3] "Wet" specimens were soaked under 1 inch of water for 24 hours.

[4] Two tests on each of five panels.

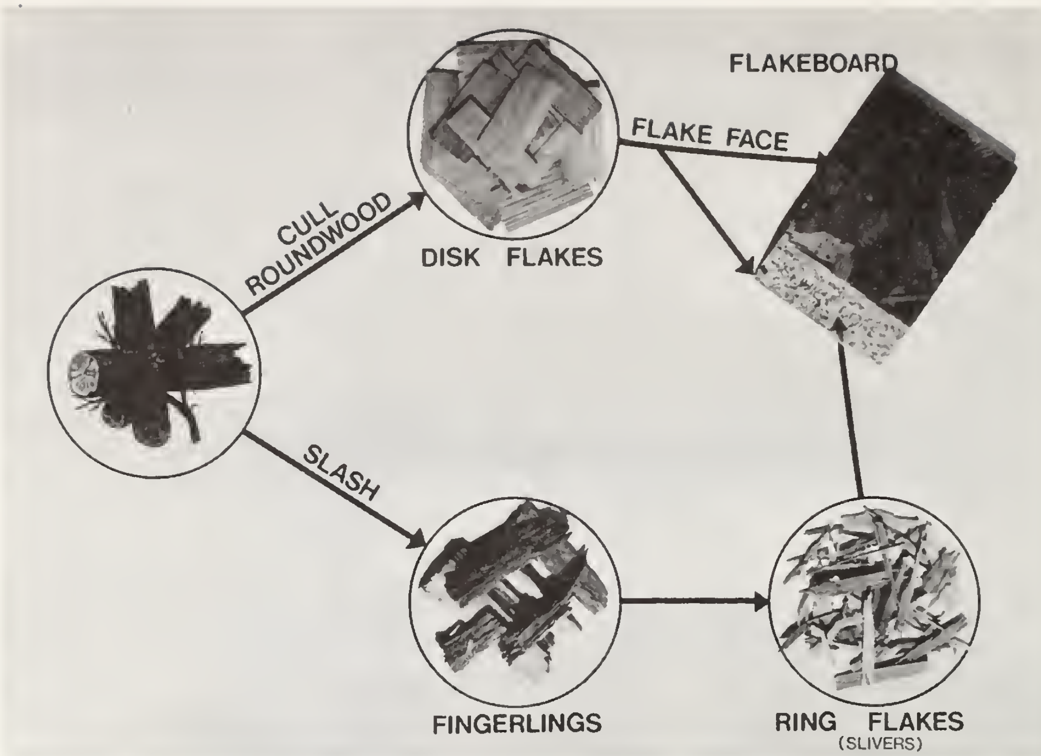

Figure 1. The forest residues-to-structural flakeboard process.

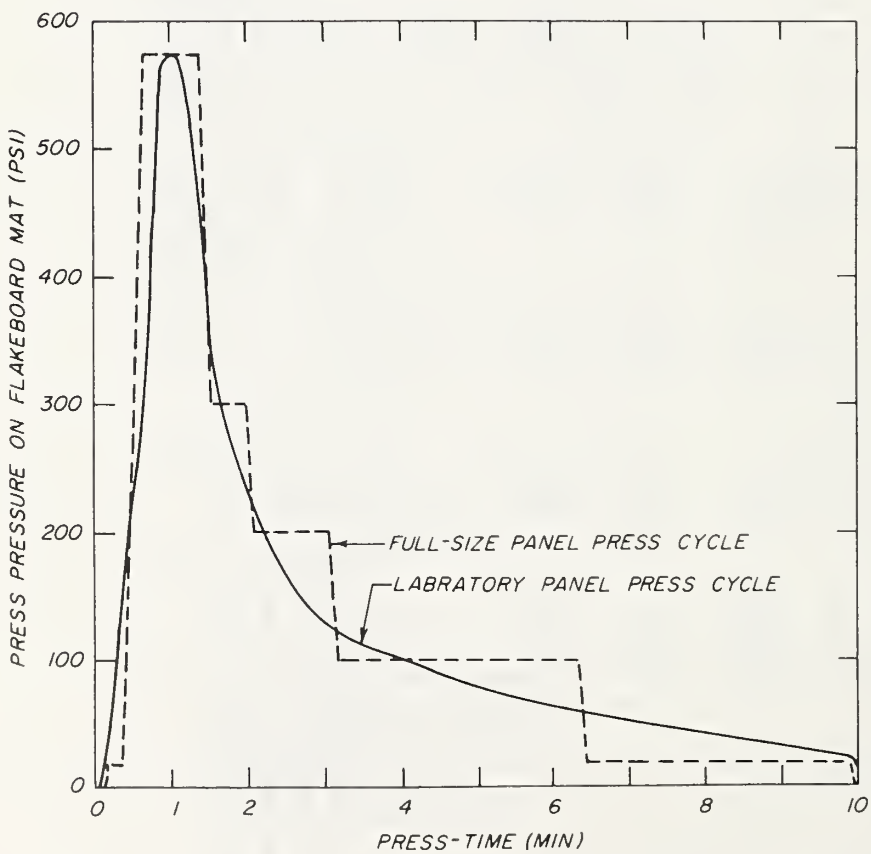

Figure 2.--Comparison of press cycles used in manufacture of laboratory and full-size structural flakeboards.

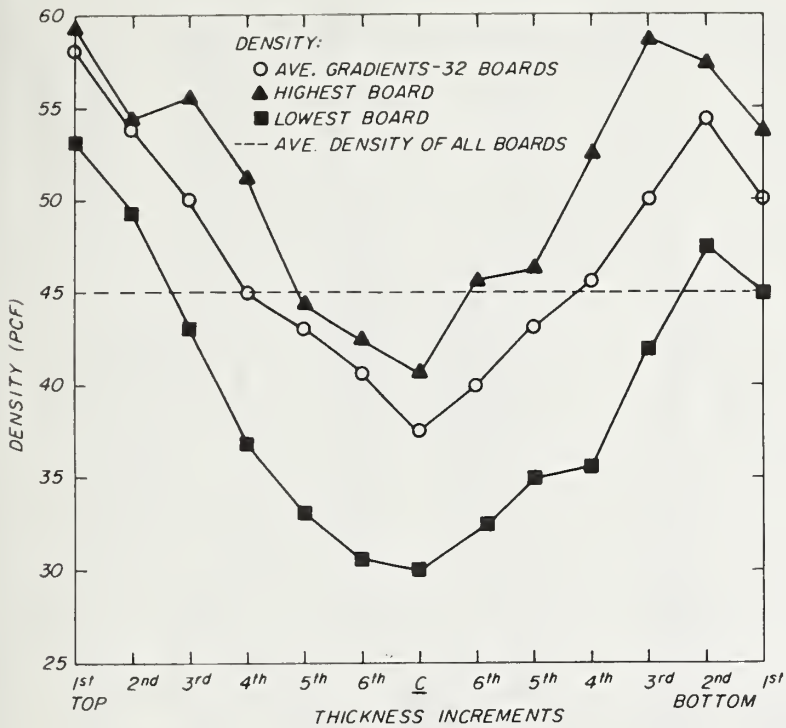

Figure 3. Density gradients through panel thickness in F.S. structural flakeboards. Density is based on weight and dimensions at 73°F, 65 percent RH.

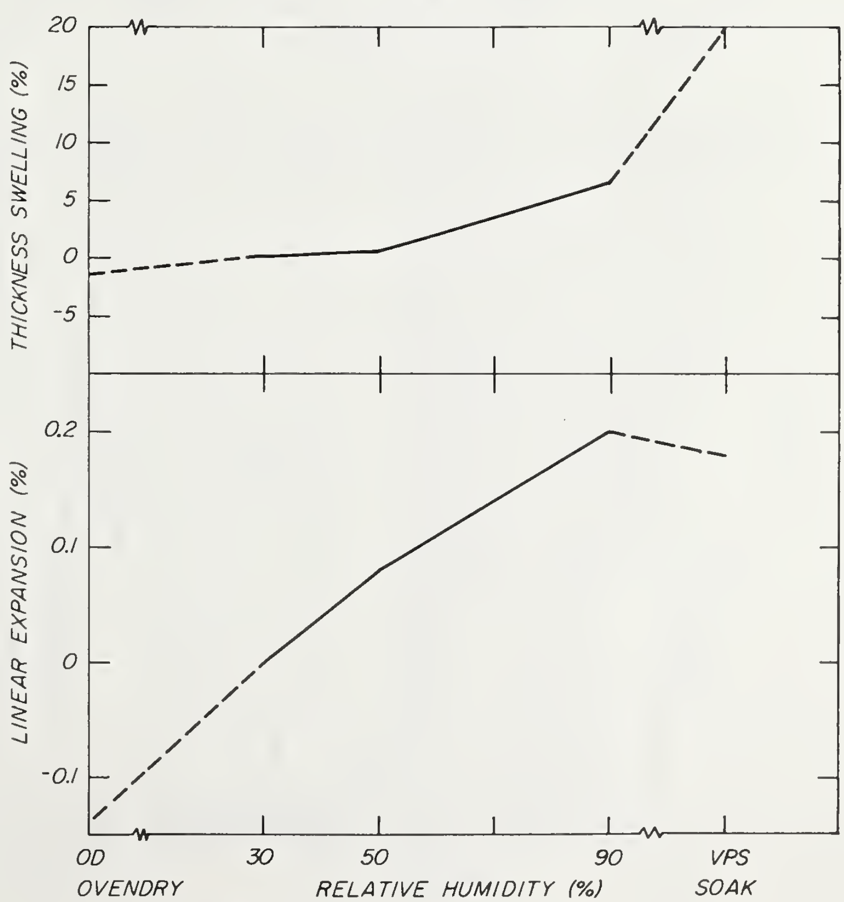

Figure 4. Relative movement in length and thickness of FPL structural flakeboard in exposures ranging from ovendry through water saturation.

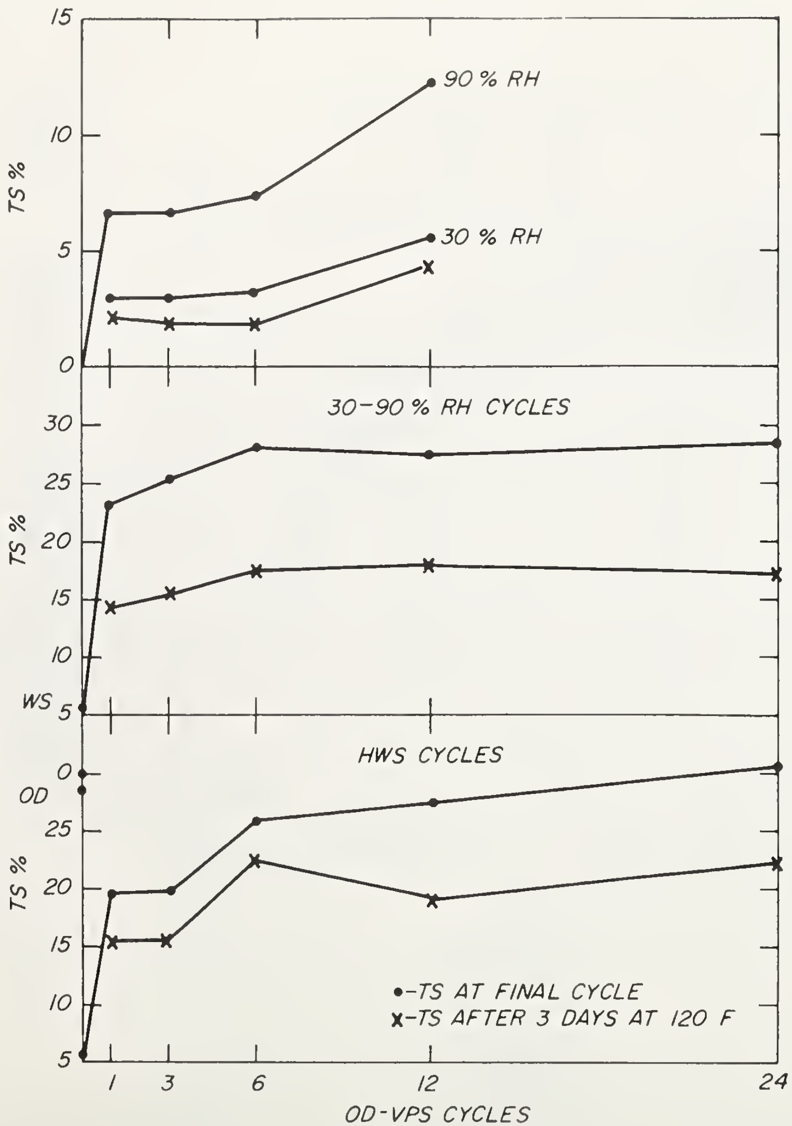

Figure 5.--Thickness swelling of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

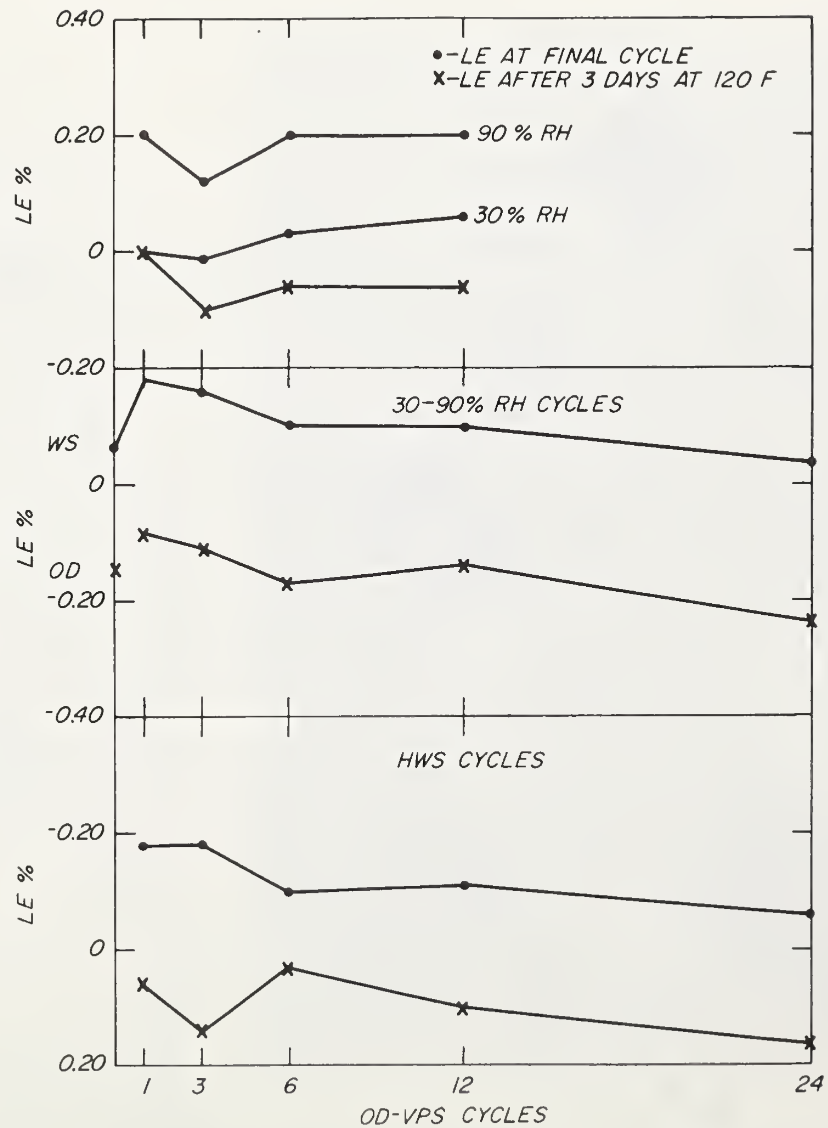

Figure 6.--Linear expansion of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

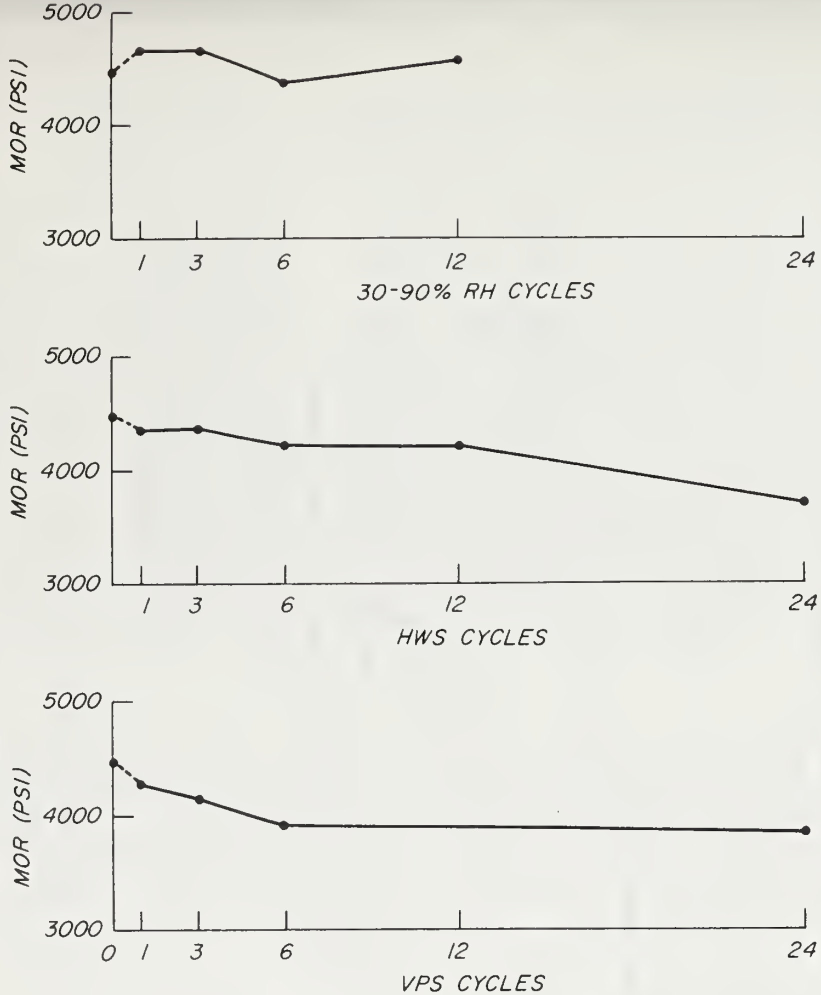

Figure 7.--Modulus of rupture of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

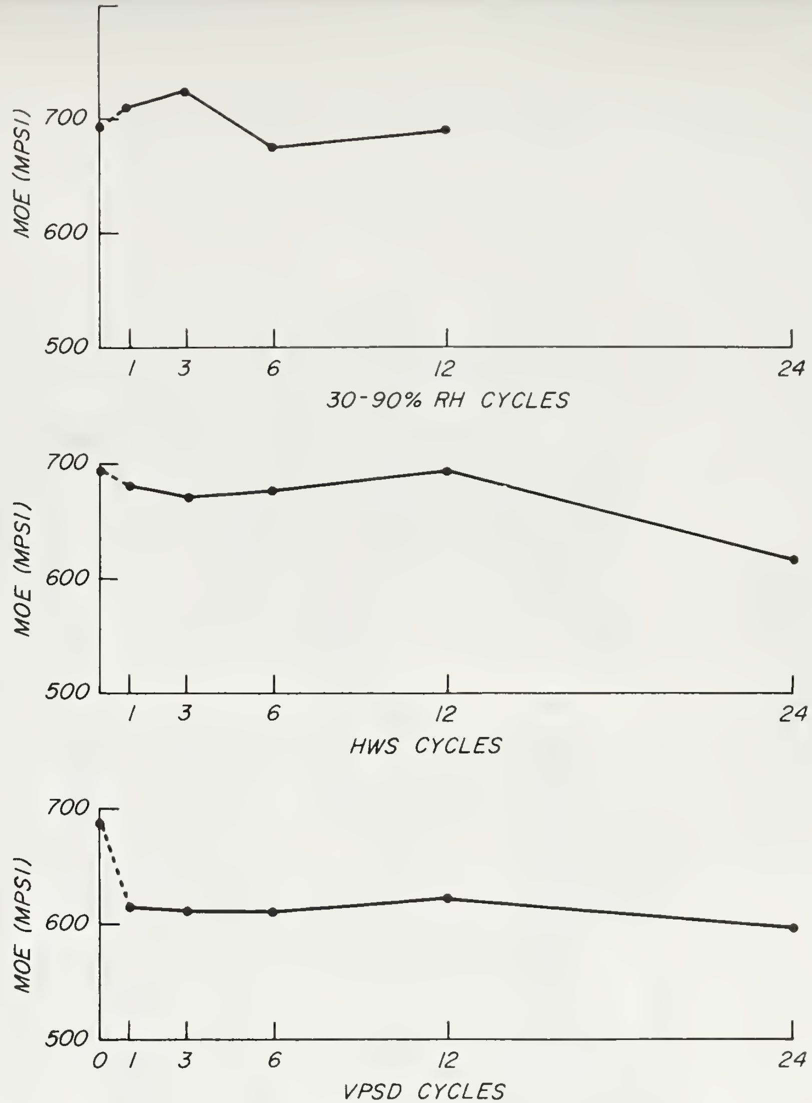

Figure 8.--Modulus of elasticity of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

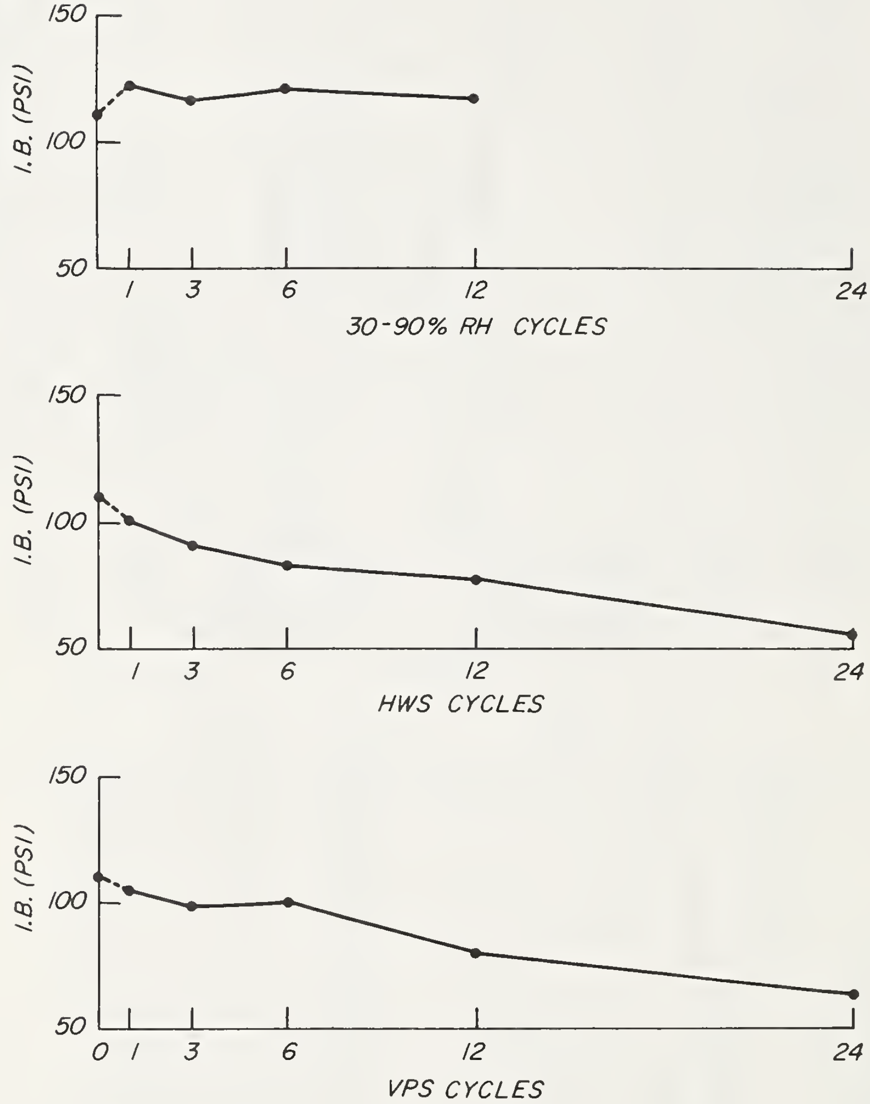

Figure 9.--Internal bond strength of FPL structural flakeboard after exposure to 1-24 cycles of three different exposures.

OVERVIEW OF STRUCTURAL FLAKEBOARD PRODUCTION COSTS

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Abstract

On the basis of experimental results with three-layer board compositions and estimates of investment and operating costs, production costs were computed using discounted cash flow techniques for 16 possible structural flakeboard manufacturing sites. The production costs computed include taxes, profits, and other selling and manufacturing costs. After computing production costs, excluding wood costs, then computing the coefficient for converting wood cost per ovendry ton to production costs including associated increases in selling, tax, and profit costs, total production costs can be expressed in "a = bX" equation form. Feasibility can then be assessed by matching expected production costs, including independent assumptions about wood costs, with likely f.o.b. mill market values for product output.

Introduction

Techniques for producing structural flakeboard products from hardwood and softwood forest residues have been determined. Unsolved, however, is the question of commercial feasibility. Preliminary analyses may be used solely to explore economic possibilities of new processes or products. Or, preliminary analyses may be used to help establish target investment costs for architectural-engineering purposes. Even after acceptable cost estimates and market forecasts are developed a number of manufacturing-marketing strategy combinations may need to be assessed before a final combination is found. For these reasons, the purpose of this paper is two-fold: (1) To describe the techniques used and the results of analysis of structural flakeboard manufacture, and (2) To announce the availability of the computer programs used for the economic analysis of structural flakeboard manufacture.

The two computer programs used to simulate structural flakeboard manufacture are named PARVCOST and CFA. Both programs, written in FORTRAN for use on Univac 1108 and 1110 systems, may be readily adapted to economic assessments of other wood products manufacturing processes.

PARVCOST Computer Program (2)

PARVCOST is a mathematical model of wood, chemical, and energy flows within an operating flakeboard plant (fig. 1). PARVCOST computes physical requirements and costs of wood, chemicals, and energy per unit of finished panel output as well as finished panel weight statistics and profit contribution (unit price minus unit variable cost) from the market value of product output. PARVCOST also computes the sensitivity of finished product costs to changes in unit costs of energy and raw materials.

PARVCOST may be used to compute the unit variable costs for discounted cash flow analyses, or may be used directly to gage the relative feasibility of manufacturing structural flakeboard between sites where raw materials, energy, and product outputs have different values but investment and operating costs are equal.

CFA Computer Program (1)

The CFS program is designed to simulate and analyze investments, costs, and revenue cash flows of manufacturing ventures for their useful or economic life (to 20 yr). Discounted cash flow analysis represents an analytical technique commonly used to generate many types of time-valued economic criteria. Truly comparable investment opportunities represent identical functional feasibilities, economic lives, risks, and financial requirements. When these conditions exist, the profit contribution computed by PARVCOST may be used as a valid criterion for assessing processing or investment alternatives. Where these conditions do not exist, the appropriate use of discounted cash flow methods will yield more useful criteria.

The CFA program is designed to compute after-tax time values of investment and operating cash flows for manufacturing ventures in terms of (1) present value of the investment, (2) internal or composite rate of return, (3) total unit cost of production, and (4) maximum investment that can be made under prescribed operating costs, revenues, and rate of return. Additionally, the CFA program is written so standardized time, investment, and rate-of-return (ROR) values can be used, and computations of the least certain elements of a manufacturing venture can be computed and used as economic criteria, such as the total cost

of production that includes tax costs and prescribed after-tax profit.

The CFA program computes both an internal ROR (IRR) and a composite ROR. The composite ROR is the rate of equity investment earning when specifying a borrowing interest rate, and short-term reinvestment for cash surplus. The IRR used for the following analyses, represents the single interest-rate situation of typical interest to a corporation capable of fully financing a new investment venture from internal resources. The IRR is the interest earnings realized as an after-tax profit with the return of principle for the financing requirements of a venture. The IRR can also be defined as the rate of interest required to discount the stream of annual net cash flows to a present value of zero.

Economic Analysis

Costs to produce flakeboard products from forest residues at 16 sites in the United States were estimated and compared with the likely market value of product output. For this study a consultant (Columbia, Eng. Intl. Inc., Eugene, Ore.) determined the equipment requirements and costs to construct operable structural flakeboard facilities and to provide estimates of operating requirements (Appendix A). From this information, operating costs were estimated and costs of panel production were computed for nine northern and seven southern sites in the United States (Fig. 2, Tables 6 and 7).

Unit costs of production include taxes, selling costs, and profit, in addition to the costs of manufacture. These costs are also the product selling prices, f.o.b. mill, required to yield a 15-percent internal rate of return (IRR) from discounted cash-flow analysis. Production costs are expressed in dollars per 1,000 square feet of product output on a 1/2-inch thickness basis (M ft^2, 1/2 in.).

Investment Requirements

The costs (1976 basis) of constructing operable structural flakeboard facilities were estimated for two climates: temperate (South) and cold (North). Facilities ranged in rated output capacities from 37.5 million square feet, 1/2-inch basis ($MMft^2$, 1/2 in.) per year to 150.0 $MMft^2$ in. per year. The smallest facility, 37.5 $MMft^2$ per year, was evaluated for three types of wood supplies: (1) wood flakes, as from a shaping lathe headrig, (2) mixtures of wood flakes and chips, and (3) mixtures of logs and chips. At least 30 percent of the structural flakeboard furnish must be of high quality flake, such as produced from roundwood using a disk flaker, or shaping lathe headrig to produce the high-strength faces required for structural flakeboard. Facilities sized from 75.0 $MMft^2$, 1/2 in. to 150.0 $MMft^2$, 1/2 in. are evaluated assuming either mixtures of flakes and chips or of logs and chips.

Two investment requirements are considered: (1) investment to establish physical facilities for structural flakeboard manufacture, and (2) working capital to cover the costs of operating inventories of raw materials, goods in process, and accounts receivable (Table 1). Average facilities costs ranged from a low of $8,384,000 to a high of $27,292,000. Working capital requirements were computed to accommodate 2 months of annual operating costs, less selling expense, for facilities supplied with chips or flakes or both; and, for 3 months for facilities supplied with logs and chips.

Production Costs

Discounted cash-flow analyses were used to compute production costs. Computer output pertaining to a 112.5 $MMft^2$, 1/2 in. per year facility utilizing flakes and chips at an Arcata, Calif., site is used as an example (Table 2). Computations were made to determine the unit selling price required to cover all costs and yield an after-tax IRR of 15 percent. The computed prices which represent full production costs for structural flakeboard included selling expense, taxes, and profit. Raw material costs were computed using the PARVCOST program, which considers wood, chemical and energy requirements and costs (Tables 3 and 4). However, because of the variability and uncertainty of wood costs, production costs were first computed that exclude wood costs. Wood costs were considered in a secondary step of the discounted cash flow analyses and will be discussed.

Labor costs for skilled and unskilled labor were increased by 30 percent to account for costs of fringe benefits. These were estimated separately for each site (Appendix B). As for other costs and revenues, labor costs were increased 5 percent per year to establish the annual cash flows used for discounted cash-flow analyses. Manning for each facility was assumed two-thirds of full requirements during the first year of operation and at full manning (3 shifts, 325 days per year) in succeeding years. Production was assumed to be 44.6 percent of capacity in the first year; 84.2 percent, in the second year, and full capacity, in succeeding years. Selling expense was computed as 10 percent of gross sales.

Administrative overhead costs include building heat, water, electricity, administrative salaries, and miscellaneous supplies and services. Factory overhead costs (computed as 8.5 percent of

facilities' costs, excluding land cost, for the first year) cover costs for maintenance labor (6%), process supplies (0.5%), local taxes (1%), and insurance (1%). Other cost factors used in the analysis include an investment tax credit (equal to 10 percent of the cost of processing equipment), depreciation (Federal Internal Revenue Service depreciation guidelines), and state and Federal revenue taxes.

For simplicity, production costs are expressed in terms of 1976 unit sales prices (Table 5). The components of costs represent the average distribution of revenues to costs over the 10 years of discounted cash-flow analysis.

Depending on the site and the size of a facility, estimated production costs, excluding wood costs, range from $107/Mft^2$, 1/2 in. to $191/Mft^2$, 1/2 in. for northern sites (Fig.3, Tables 6 and 7). Economics of large scale operations represent gains primarily in processing labor productivity and increased efficiency of administrative and maintenance requirements. Efficiencies gained by using large press sizes in the large facilities reduce trim losses, and glue, wax, and energy requirements. The gain in efficiency of the largest press size considered (8- by 24-ft) over the smallest (4- by 8-ft) is estimated to represent cost savings from $2 to $3/Mft^2$, 1/2 in. Efficiency of resin and wax use range from 88.6 percent for the 4- by 8-foot press to 94.7 percent for the 8- by 24-foot press. Efficiency of wood use for both softwoods and hardwoods ranges from about 80.0 percent for the 4- by 8-foot press to about 82.5 percent for the 8- by 24-foot press.

Estimated costs for 75.0 $MMft^2$, 1/2 in.* facilities are about 40 percent greater than the costs for 37.5 $MMft^2$, 1/2 in.* facilities, and yield production costs about 23 percent less. Costs for 112.5 $MMft^2$, 1/2 in.* facilities are about 28 percent greater than those for 75.0 $MMft^2$, 1/2 in.* facilities, and production costs are about 10 percent less. A 150.0 $MMft^2$, 1/2 in. facility cost about 33 percent more than a 112.5 $MMft^2$, 1/2 in. facility but only reduces production costs about 2 percent.

Wood Costs

Wood costs were analyzed separately from other production costs. An average of about 1.06 ovendry tons (ODT) of softwood raw material is needed to produce 1,000 square feet of 1/2-inch-thick panel (Mft^2, 1/2 in.) (gross shipping weight of about 1,900 pounds/Mft^2, 1/2 in. at 7 percent moisture content (MC)). For hardwoods, about 1.18 ODT of wood are needed to produce 1,000 square feet of 1/2-inch-thick panel (gross shipping weight of about 2,200 pounds/Mft^2, 1/2 in. at 7 percent MC). Wood cost for 1/2-inch panel, per thousand square feet, is then about 6 percent more than the cost of wood raw materials per ODT for softwoods, and about 18 percent more for hardwoods. To translate wood cost into production costs, selling expense (10 pct.) and increases in profits and taxes to cover financing costs (15 pct.) for increases in working capital requirements were added to the cost of the wood (Table 5). The production cost for wood per Mft^2, 1/2 in. therefore ranges from 1.17 to 1.43 times that of wood raw materials per ODT. (The costs depend on efficiency of facility and average density of wood raw materials).

Because concentrations of forest residue-type materials and their size and shape, and distance from their point of use are highly variable, costs of harvesting and transporting these materials are also highly variable. Estimates of wood costs prepared for the 16 sites indicate wood costs may range from $13 to $41/ODT.

Production Costs--Inclusive of Wood Cost

After computing costs of structural flakeboard production, excluding wood costs, and after computing the coefficient for converting wood cost per ODT to production costs that include additional selling expense, taxes, profit and costs, total production costs can be expressed in equation form:

$$PC = a + bX$$

where,

PC is production cost ($/Mft^2$, 1/2 in.); a, production cost excluding wood cost ($/Mft^2$, 1/2 in.); and b coefficient of wood cost per ODT, X for calculating wood cost per Mft^2, 1/2 in.

Production costs, including wood cost, can then be readily calculated as a function of highly variable wood costs necessarily considered for computing total production costs for structural flakeboard (Tables 6 and 7).

Assessment of Feasibility

Preliminary assessments of commercial feasibility can be made by matching expected production costs of structural flakeboard against likely f.o.b. mill value of product output (Fig. 4). For example, the 112.5 $MMft^2$, 1/2 in. per year facility utilizing flakes and chips at an Arcata, Calif. site had estimates of total production costs, including wood costs, ranging from about $151/Mft^2$, 1/2 in. to $154/Mft^2$, 1/2 in. for wood costs from $30/ODT to $33/ODT. The market

*Annual rated capacity, 3 shifts, 325 days per year.

value, f.o.b. mill, for panel output was estimated (1976) to be about (167/Mft^2, 1/2 in.

Although some structural flakeboard might be sold for specialty use as siding and decorative panel use, the primary opportunity is probably for marketing commodity grades of structural sheathing. Of these products, CD exterior grade, 1/2-inch-thick plywood is the most predominant product in use. For structural flakeboard products to compete in the commodity sheathing markets, they will probably have to be sold at or below prevailing market costs for comparable plywood sheathing materials. The market value, f.o.b. Arcata, Calif.,is based on the average market price of CD exterior grade 1/2-inch-thick plywood sheathing f.o.b. Los Angeles, less the higher cost of structural flakeboard. At most, the market value of structural flakeboard might cover a maximum wood cost of about $44/ODT.

Commercial feasibility can also be assessed by matching likely wood supply costs to the maximum wood costs that could be covered by estimated mill market price for panel output. These values can be calculated by subtracting the production costs, excluding wood cost, from the f.o.b. mill market value for panel output and dividing the remainder by the coefficient of wood cost per ODT to yield a maximum supportable wood cost per ODT.

Other aspects of commercial feasibility exist in addition to the analyses presented in this paper. Additional analyses might consider proprietary and intangible aspects that may influence feasibility. It is also possible that by modifying a largely depreciated particleboard facility to produce structural flakeboard, investment and production costs may be greatly reduced.

Summary and Conclusions

Forest Service research has shown structural flakeboard products can be produced from hardwood and softwood forest residue-type materials. Panel test results indicate strength properties of experimental boards produced from forest residue-type materials are suitable for use in engineered applications. In this analysis of the manufacturing costs of experimental three-layer flakeboard compositions and estimates of investment and operating costs, production costs were computed for 16 possible structural flakeboard sites in north and south regions of the United States. Large economics of scale were indicated by evaluating four sizes of facilities.

Production costs computed for manufacturing structural flakeboard include taxes and profits, as well as other manufacturing costs. By computing structural flakeboard production costs, excluding wood costs; then computing the coefficient for converting wood cost per ovendry ton to production costs that include additional selling expense and tax and profit costs, total production costs were expressed in equation form. A method was presented to calculate production costs, including wood cost, as a function of wood costs--the most variable element considered.

Assessments of feasibility was made by matching expected production costs against likely f.o.b. mill value of product output. Also, it was shown how commercial feasibility may be more directly assessed by matching likely wood supply costs to the maximum wood costs supportable by estimated f.o.b. mill market value for panel output.

In the analyses presented here the stature of preliminary assessments is assumed in which actual pre-investment analyses must consider proprietary and intangible aspects not considered. Additionally, it is suggested that, when possible, by remodeling a largely depreciated particleboard facility for production of structural flakeboard, investment and production costs may be greatly reduced.

References

1. Harpole, George B. 1978. Cash flow analysis computer program for analyzing manufacturing investment. USDA For. Serv. Res. Pap. FPL-305.

2. Ince, Peter J., and George B. Harpole. 1977. PARVCOST: A Particleboard Variable Cost Program. USDA For. Serv. Gen. Tech. Rep. FPL 14, 26. p.

Appendix A
Estimates of capital investment costs for four sizes of structural flakeboard facilities

In April 1976, the Forest Products Laboratory (U.S. Department of Agriculture) at Madison, Wisconsin retained Columbia Engineering International, Inc. of Eugene, Oregon to investigate the capital costs of plants designed to produce structural grade flakeboards. Preceeding this study, an extensive research program had been initiated within the U.S. Forest Service research organization to determine the raw material, processing and equipment requirements of plants suitable for manufacture of structural grade panel products from forest residue-type materials. The plant designs and capital costs developed by Columbia's study were based partly on the data supplied from Forest Service research and partly from Columbia's past experience in the design, construction and operation

of structural grade as well as industrial grade particleboard plants.

The engineering study Columbia Engineering International, Inc. completed resulted in the definition of basic or standard plant-components which may be utilized in the design of a wide range of plant design parameters. In the pages that follow, the selection of plant configurations used for economic analysis are summarized in terms of their construction costs (1976 basis) and depreciation schedules. This selection of plant designs represent facilities with annual output capacities ranging from 37.5 million square feet, 1/2-inch basis, to 150.0 million square feet, 1/2-inch basis. Additionally, each facility size is represented by a design suitable for siting in intemperate climatic conditions typical of northern latitudes of the United States (excluding Alaska), designated North, and for siting in temperate climates typical of the southern latitudes of the United States, designated South. The difference in facilities designed for North and South sites is found in the amount of shelter and thermal protection provided for raw materials in storage and processing operations. Each facility is also designed for the utilization of roundwood, chips and/or flakes. Operating requirements, and cost estimates used for the economic analysis of each facility are given in Appendix B.

PERSONNEL REQUIREMENTS

Press Size	4' X 8'	4' X 16'	4' X 24'	8' X 24'
Annual output (million ft^2, ½")	37.5	75.0	112.5	150.0
	- - - - - - - - - - - Number of persons - - - - - - - - - - -			
Administrative personnel				
Manager	1	1	1	1
Supervisor	1	1	1	1
Engineer	-	1	1	1
Office manager	1	1	1	1
Technical director	1	1	1	1
Shipper	1	1	1	1
Purchasing agent	1	1	1	1
Clerical	4	4	4	4
Foremen	3	3	5	6
Total	13	14	16	17
Processing personnel[1/]				
- 100% flakes				
Skilled labor	29			
Unskilled labor	4			
Total	33			
- 40% flakes, 60% chips				
Skilled labor	31	34	43	49
Unskilled labor	4	6	6	8
Total	35	40	49	57
- 40% logs, 60% chips				
Skilled labor	39	43	53	63
Unskilled labor	5	8	11	12
Total	44	51	64	75

[1/] Maintenance personnel requirements are not included. All maintenance and repair costs are included in factory overhead costs at 6.5% of facilities capital cost, excluding land cost.

FACILITY (CAPITAL COSTS) AND DEPRECIATION ALLOWANCES ($1,000)

Press size: 4- by 8-foot, 24 openings

Annual output (½-inch basis): 37.5 MMSF

Annual wood requirement (cubic feet): 2.6-3.3 $MMft^3$/100% flakes

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (30 acres)[1]	----	----	----	----	----	----	----
Land improvements	(288)	14.4	14.4	14.4	14.4	14.4	14.4
Buildings	(840)	18.7	18.7	18.7	18.7	18.7	18.7
Processing equipment	(6,988)	1,257.8	1,006.3	805.0	644.0	515.2	412.2
Mobile equipment:							
1st 5 years	(140)	25.2	25.2	25.2	25.2	25.2	
2nd 5 years						(178.7)	34.7
Totals[1]	(8,316)	1,316.1	1,122.9	863.3	702.3	573.5	480.0

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (30 acres)[1]	----	----	----	----	----	----	----
Land improvements	(258)	12.9	12.9	12.9	12.9	12.9	12.9
Buildings	(582)	12.9	12.9	12.9	12.9	12.9	12.9
Processing equipment	(6,791)	1,222.4	977.9	782.3	625.9	500.7	400.5
Mobile equipment:							
1st 5 years	(140)	25.2	25.2	25.2	25.2	25.2	
2nd 5 years						(178.7)	34.7
Totals[1]	(7,831)	1,273.4	1,028.9	833.3	676.9	551.7	461.0

[1] See appendix B for land cost estimates for each site.

FACILITY (CAPITAL COSTS) AND DEPRECIATION ALLOWANCES ($1,000)

Press size: 4- by 8-foot, 24 openings

Annual output (½-inch basis): 37.5 MMSF

Annual wood requirement (cubic feet): 2.6-3.3 $MMft^3$/40% flakes, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (30 acres)[1]	----	-----	----	----	----	----	----
Land improvements	(292)	14.6	14.6	14.6	14.6	14.6	14.6
Buildings	(885)	19.6	19.6	19.6	19.6	19.6	19.6
Processing equipment	(8,060)	1,450.8	1,160.6	928.5	742.8	594.2	475.4
Mobile equipment:							
1st 5 years	(240)	43.2	43.2	43.2	43.2	43.2	
2nd 5 years						(306.3)	59.5
Totals[1]	(9,537)	1,528.2	1,238.0	1,005.9	820.2	671.6	569.1

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (30 acres)[1]	----	----	----	----	----	----	----
Land improvements	(266)	13.3	13.3	13.3	13.3	13.3	13.3
Buildings	(615)	13.7	13.7	13.7	13.7	13.7	13.7
Processing equipment	(7,839)	1,411.0	1,128.8	903.1	722.4	578.0	462.4
Mobile equipment:							
1st 5 years	(240)	43.2	43.2	43.2	43.2	43.2	
2nd 5 years						(306.3)	59.5
Totals[1]	(9,020)	1,481.2	1,1990.0	973.3	792.6	648.2	548.9

Press size: 4- by 8-foot, 24 openings

Annual output (½-inch basis): 37.5 MMSF

Annual wood requirement (cubic feet): 2.6-3.3 $MMft^3$/40% logs, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (35 acres)[1]	----	----	----	----	----	----	----
Land improvements	(301)	15.1	15.1	15.1	15.1	15.1	15.1
Buildings	(1,005)	22.3	22.3	22.3	22.3	22.3	22.3
Processing equipment	(9,759)	1,756.6	1,405.3	1,124.2	899.4	719.5	575.6
Mobile equipment:							
1st 5 years	(415)	74.7	74.7	74.7	74.7	74.7	
2nd 5 years						(529.7)	102.8
Totals[1]	(11,550)	1,868.7	1,517.4	1,236.3	1,011.5	831.6	715.8

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (35 acres)[1]	----	----	----	----	----	----	----
Land improvements	(277)	13.9	13.9	13.9	13.9	13.9	13.9
Buildings	(615)	13.7	13.7	13.7	13.7	13.7	13.7
Processing equipment	(9,513)	1,712.3	1,369.9	1,095.9	876.7	701.4	561.1
Mobile equipment:							
1st 5 years	(415)	74.7	74.7	74.7	74.7	74.7	
2nd 5 years						(529.7)	102.8
Totals[1]	(10,890)	1,814.6	1,472.2	1,198.2	979.0	803.7	691.5

[1] See appendix B for land cost estimates for each site.

FACILITY (CAPITAL COSTS) AND DEPRECIATION ALLOWANCES ($1,000)

Press size: 4- by 16-foot, 24 openings

Annual output (½-inch basis): 75.0 MMSF

Annual wood requirement (cubic feet): 5.2-6.5 MMft³/40% flakes, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (40 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(388)	19.4	19.4	19.4	19.4	19.4	19.4
Buildings	(1,479)	32.9	32.9	32.9	32.9	32.9	32.9
Processing equipment	(11,333)	2,039.9	1,632.0	1,305.6	1,044.4	835.6	668.4
Mobile equipment:							
1st 5 years	(250)	45	45	45	45	45	
2nd 5 years						(319.1)	61.9
Totals[1/]	(13,530)	2,137.2	1,729.3	1,402.9	1,141.7	932.9	782.6

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (40 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(373)	18.7	18.7	18.7	18.7	18.7	18.7
Buildings	(1,029)	22.9	22.9	22.9	22.9	22.9	22.9
Processing equipment	(11,138)	2,004.8	1,603.9	1,283.1	1,026.5	821.2	656.9
Mobile equipment:							
1st 5 years	(250)	45	45	45	45	45	
2nd 5 years						(319.1)	61.9
Totals[1/]	(12,870)	2,091.4	1,690.5	1,369.7	1,113.1	907.8	760.4

Press size: 4- by 16-foot, 24 openings

Annual output (½-inch basis): 75.0 MMSF

Annual wood requirement (cubic feet): 5.2-6.5 MMft³/40% logs, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (60 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(418)	20.9	20.9	20.9	20.9	20.9	20.9
Buildings	(1,856)	41.2	41.2	41.2	41.2	41.2	41.2
Processing equipment	(13,241)	2,383.4	1,906.7	1,525.4	1,220.3	976.2	780.9
Mobile equipment:							
1st 5 years	(425)	76.5	76.5	76.5	76.5	76.5	
2nd 5 years						(542.4)	105.3
Totals[1/]	(16,060)	2,522.0	2,045.3	1,664.0	1,358.9	1,114.8	948.3

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (60 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(383)	19.2	19.2	19.2	19.2	19.2	19.2
Buildings	(1,076)	23.9	23.9	23.9	23.9	23.9	23.9
Processing equipment	(12,894)	2,320.9	1,856.7	1,485.4	1,188.3	950.6	760.5
Mobile equipment:							
1st 5 years	(425)	76.5	76.5	76.5	76.5	76.5	
2nd 5 years						(542.4)	105.3
Totals[1/]	(14,898)	2,440.5	1,976.3	1,605.0	1,307.9	1,070.2	908.9

[1/] See appendix B for land cost estimates for each site.

FACILITY (CAPITAL COSTS) AND DEPRECIATION ALLOWANCES ($1,000)

Press size: 4- by 24-ft, 24 openings

Annual output (½-inch basis): 112.5 MMSF

Annual wood requirement (cubic feet): 7.7-9.7 MMft^3/40% flakes, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (70 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(461)	23.1	23.1	23.1	23.1	23.1	23.1
Buildings	(2,045)	45.5	45.5	45.5	45.5	45.5	45.5
Processing equipment	(14,444)	2,599.9	2,079.9	1,663.9	1,331.1	1,064.9	851.9
Mobile equipment:							
1st 5 years	(290)	52.2	52.2	52.2	52.2	52.2	
2nd 5 years						(370.1)	71.8
Totals[1/]	(17,380)	2,720.7	2,200.7	1,784.7	1,451.9	1,185.7	992.3

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (70 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(427)	21.4	21.4	21.4	21.4	21.4	21.4
Buildings	(1,360)	30.2	30.2	30.2	30.2	30.2	30.2
Processing equipment	(14,173)	2,551.1	2,040.9	1,632.7	1,306.2	1,044.9	835.6
Mobile equipment:							
1st 5 years	(290)	52.2	52.2	52.2	52.2	52.2	
2nd 5 years						(370.1)	71.8
Totals[1/]	(16,390)	2,654.9	2,144.7	1,736.5	1,410.0	1,148.7	959.0

Press size: 4- by 24-foot, 24 openings

Annual output (½-inch basis): 112.5 MMSF

Annual wood requirement (cubic feet): 7.7-9.7 MMft^3/40% logs, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (100 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(512)	25.6	25.6	25.6	25.6	25.6	25.6
Buildings	(2,538)	56.4	56.4	56.4	56.4	56.4	56.4
Processing equipment	(16,855)	3,033.9	2,427.1	1,941.7	1,553.4	1,242.7	994.1
Mobile equipment:							
1st 5 years	(465)	83.7	83.7	83.7	83.7	83.7	
2nd 5 years						(593.5)	115.2
Totals[1/]	(20,570)	3,199.6	2,592.8	2,107.4	1,719.1	1,408.4	1,191.3

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (100 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(473)	23.7	23.7	23.7	23.7	23.7	23.7
Buildings	(1,391)	30.9	30.9	30.9	30.9	30.9	30.9
Processing equipment	(16,171)	2,910.8	2,328.6	1,862.9	1,490.3	1,192.3	953.8
Mobile equipment:							
1st 5 years	(465)	83.7	83.8	83.7	83.7	83.7	
2nd 5 years						(593.5)	115.2
Totals[1/]	(18,700)	3,049.1	2,466.9	2,001.2	1,628.6	1,330.6	1,092.1

1/ See appendix B for land cost estimates for each site.

FACILITY (CAPITAL COSTS) AND DEPRECIATION ALLOWANCES ($1,000)

Press size: 8- by 24-foot, 16 openings

Annual output (½-inch basis): 150.0 MMSF

Annual wood requirement (cubic feet): 10.0-12.6 $MMft^3$/40% flakes, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (100 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(625)	31.3	31.3	31.3	31.3	31.3	31.3
Buildings	(2,730)	50.7	50.7	50.7	50.7	50.7	50.7
Processing equipment	(19,785)	3,561.3	2,849.0	2,279.2	1,823.4	1,458.7	1,167.0
Mobile equipment:							
1st 5 years	(310)	55.8	55.8	55.8	55.8	55.8	
2nd 5 years						(395.7)	76.8
Totals[1/]	(23,650)	3,699.1	2,986.8	2,417.0	1,961.2	1,596.5	1,325.8

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (100 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(545)	27.3	27.3	27.3	27.3	27.3	27.3
Buildings	(1,679)	37.3	37.3	37.3	37.3	37.3	37.3
Processing equipment	(18,993)	3,418.7	2,735.0	2,188.0	1,750.4	1,400.3	1,120.3
Mobile equipment:							
1st 5 years	(310)	55.8	55.8	55.8	55.8	55.8	
2nd 5 years						(395.7)	76.8
Totals[1/]	(21,727)	3,539.1	2,885.4	2,308.4	1,870.8	1,520.7	1,261.7

Press size: 8- by 24-foot, 16 openings

Annual output (½-inch basis): 150.0 MMSF

Annual wood requirement (cubic feet): 10.1-12.6 $MMft^3$/40% logs, 60% chips

Northern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (150 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(695)	34.8	34.8	34.8	34.8	34.8	34.8
Buildings	(3,220)	71.6	71.6	71.6	71.6	71.6	71.6
Processing equipment	(22,200)	3,996.0	3,196.8	2,557.4	2,046.0	1,636.8	1,309.4
Mobile equipment:							
1st 5 years	(535)	96.3	96.3	96.3	96.3	96.3	
2nd 5 years						(682.8)	132.5
Totals[1/]	(26,950)	4,198.7	3,399.5	2,760.1	2,248.7	1,839.5	1,548.3

Southern Sites

Year	(Capital Costs) 1976	Depreciation 1976	1977	1978	1979	1980	1981-1985
Land (150 acres)[1/]	----	----	----	----	----	----	----
Land improvements	(610)	34.8	34.8	34.8	34.8	34.8	34.8
Buildings	(1,720)	38.2	38.2	38.2	38.2	38.2	38.2
Processing equipment	(21,159)	3,808.6	3,046.9	2,437.5	1,950.0	1,560.0	1,248.0
Mobile equipment:							
1st 5 years	(535)	96.3	96.3	96.3	96.3	96.3	
2nd 5 years						(682.8)	132.5
Totals[1/]	(24,324)	3,977.9	3,216.2	2,606.8	2,119.3	1,729.3	1,453.5

1/ See appendix B for land cost estimates for each site.

Appendix B.--Personnel, chemical, energy, and land costs--1976 basis.

	Northern Sites						(continued)
	St. Anthony, Idaho	Virginia, Minnesota	Western Montana	LaGrande, Oregon	Medford, Oregon	Southern Vermont	Longview, Washington
Personnel costs							
Administrative personnel 1/		- - - - - - - dollars per year - - - - - - -					
Manager	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Supervisor	25,500	25,000	25,000	25,000	25,000	25,000	25,000
Engineer	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Office manager	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Technical director	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Shipper	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Purchasing agent	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Clerical	6,000	7,000	10,820	7,400	7,400	7,400	7,400
Foremen	13,500	11,560	13,500	14,400	14,400	12,000	14,400
Processing personnel 1/		- - - - - - - dollars per hour - - - - - - -					
Skilled labor	5.50	5.80	5.80	5.90	5.90	4.45	5.90
Unskilled labor	5.00	5.25	4.93	5.10	5.10	4.00	5.10
Chemical costs		- - - - - cents per pound, solids- - - - - -					
Liquid phenolic resin	29	29	28	29	29	33	29
Emulsified wax	19	19	19	19	19	19	19
Energy costs		- - - - - cents per kilowatt hour- - - - - -					
Electricity	1.25	2.0	1.25	1.5	1.25	2.5	1.5
		- - - - - dollars per 6 X 10^6 Btu's- - - - -					
Oil	12.50	14.25	12.50	15.50	15.50	15.50	15.50
Land costs		- - - - - - - -dollars per acre- - - - - - -					
	1,000	1,500	10,000	5,000	5,000	2,000	5,000

1/Thirty percent added to cover fringe benefits.

Personnel, chemical, energy and land costs--1976 basis

	Northern Sites		Southern Sites						
	Northern West Virginia	Laramie, Wyoming	Arcata California	South Central Georgia	Cornish Mississippi	Southern Missouri	Oak Ridge, Tennessee	Southeastern Tennessee	East Texas
Personnel costs									
Administrative personnel 1/				- - - - - - - dollars per year - - - - - - -					
Manager	30,000	30,000	30,000	26,000	25,000	25,000	25,000	25,000	25,000
Supervisor	30,000	25,000	25,000	21,000	18,000	18,000	18,000	20,000	18,000
Engineer	12,000	15,000	15,000	12,000	12,000	12,000	12,000	12,000	12,000
Office manager	10,000	12,000	12,000	11,000	10,000	10,000	10,000	10,000	10,000
Technical director	10,000	12,000	12,000	11,000	10,000	10,000	10,000	10,000	10,000
Shipper	8,000	10,000	10,000	9,000	8,000	8,000	8,000	7,900	8,000
Purchasing agent	10,000	12,000	12,000	10,000	10,000	10,000	10,000	10,000	10,000
Clerical	7.700	5,800	7,400	8,160	6,320	9,800	6,800	7,900	9,800
Foremen	12,000	14,000	14,400	14,500	12,000	14,000	12,000	15,000	14,000
Processing personnel 1/				- - - - - - - dollars per year - - - - - - -					
Skilled labor	2.83	4.35	6.20	4.10	3.40	4.90	4.00	4.00	4.90
Unskilled labor	2.68	4.05	5.35	3.60	2.80	3.50	3.25	3.15	3.50
Chemical costs				- - - - - cents per pound, solids- - - - - -					
Liquid phenolic resin	25	30	30	25	29	25	29	25	. 25
Emulsified wax	19	19	19	19	19	19	19	19	19
Energy costs				- - - - - cents per kilowatt hour- - - - - -					
Electricity	4.5	1.0	2.0	2.21	1.8	3.0	1.8	1.99	3.0
				- - - - dollars per 6 X 10^6 Btu's- - - - - -					
Oil	20.90	12.50	15.50	13.80	17.50	16.50	14.50	11.80	16.50
Land costs				- - - - - - - dollars per acre - - - - - - -					
	1,000	8,000	3,500	700	1,500	1,000	2,500	1,200	1,000

1/ Thirty percent added to cover fringe benefits.

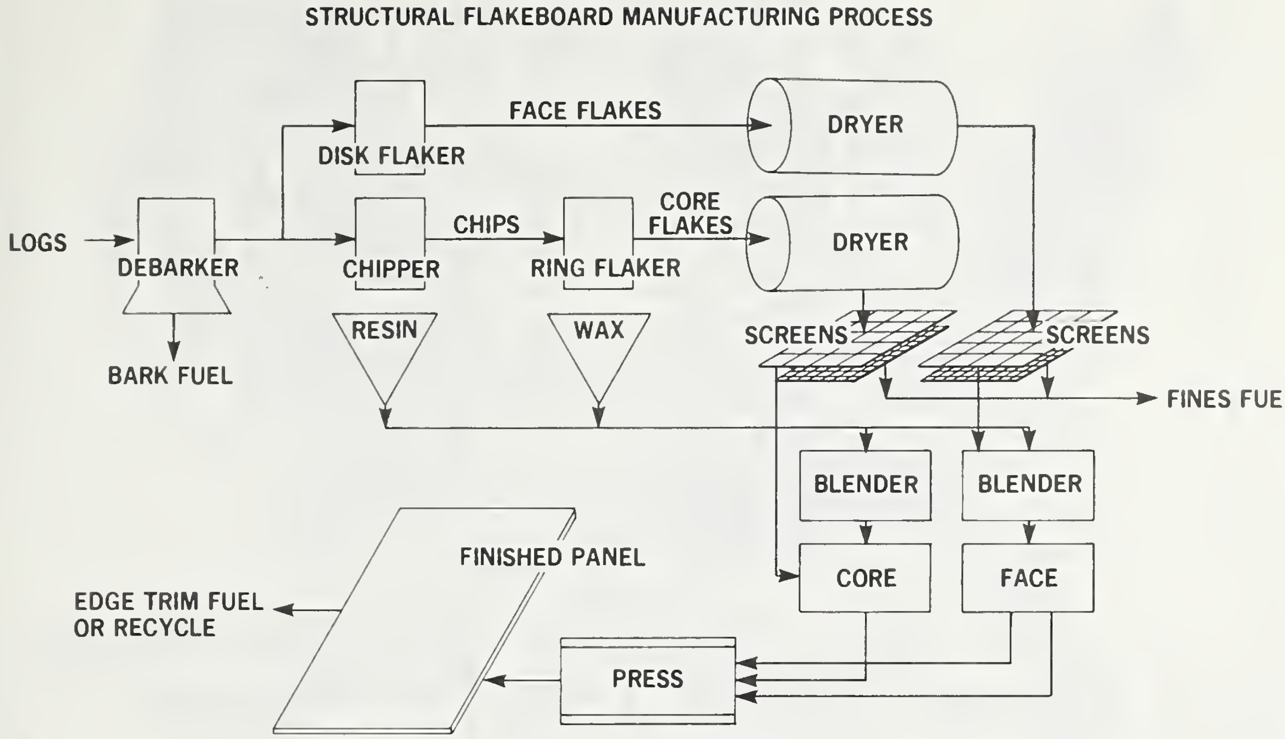

Figure 1.--Structural flakeboard manufacturing process.

Table 1.--Average investment requirements for manufacturing structural flakeboard, 1976 basis.

	Annual output capacity, MMSF, 1/2 in. basis							
	37.5[1/]		75.0[2/]		112.5[3/]		150.0[4/]	
	N[5/]	S[5/]	N	S	N	S	N	S
	---Dollars, 1000---							
100 PERCENT FLAKES								
Facilities	8,384	7,820						
Working capital	446	388						
Total	8,830	8,208						
40 PERCENT FLAKES, 60 PERCENT CHIPS								
Facilities	9,605	9,009	13,621	12,855	17,539	16,364	23,878	21,690
Working capital	468	422	758	654	1,058	907	1,373	1,177
Total	10,073	9,431	14,379	13,509	18,597	17,271	25,251	22,867
40 PERCENT LOGS, 60 PERCENT CHIPS								
Facilities	11,630	10,877	16,197	14,876	20,798	18,663	27,292	24,268
Working capital	747	648	1,203	1,024	1,666	1,402	2,143	1,797
Total	12,377	11,525	17,400	15,900	22,464	20,065	29,435	26,065

1/ Press size: 4- by 8-ft.
2/ Press size: 4- by 16-ft.
3/ Press size: 4- by 24-ft.
4/ Press size: 8- by 24-ft.
5/ N, north; S, south.

Table 2.--Example of discounted cash-flow analysis used for assessing production costs

STRU. F.B.(SOUTH)**112.5 MMSF-1/2, 4X24 PRESS, FLAKES AND CHIPS **ARCATA, CALIF. (X-WOOD)
(INVESTMENT TAX CREDIT OF $1417300. CONSIDERED.)

INITIAL INVESTMENT--YEAR 0		EFFECTIVE TAX RATE	.5268	ORIGINAL CASH EQUITY	$ 0.	VAR. COSTS/SALES =	.4849
FACILITIES COST	$16495000.	BORROWING RATE	.0000	ENDING VALUE OF EQUITY	$20673655.	FIXED COSTS/SALES=	.2441
WORKING CAPITAL	$ 689154.	REINVESTMENT RATE	.0000	FACILITIES SALVAGE VALUE	$ 2975300.	TAX COSTS/SALES =	.1333
TOTAL INVEST.	$17184154.	INTERNAL ROR	.1500	P.V. OF INVST.(I=.1500)	$ 8.	A.T. PROFIT/SALES=	.1377

OPERATING CASH FLOWS

YEAR-END VALUES . . .		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
UNIT SALES		50175.	94680.	112500.	112500.	112500.	112500.	112500.	112500.	112500.	112500.
UNIT PRICE	$	112.57 $	118.20 $	124.11 $	130.31 $	136.83 $	143.67 $	150.85 $	158.40 $	166.31 $	174.63
GROSS SALES	$	5648124.$	11190863.$	13962010.$	14660109.$	15393115.$	16162771.$	16970909.$	17819455.$	18710428.$	19645948.
INTEREST INC-EXP		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
GROSS REVENUES	$	5648124.$	11190883.$	13962010.$	14660109.$	15393115.$	16162771.$	16970909.$	17819455.$	18710428.$	19645948.
RAW MATERIAL COST	$	1838512.$	3642728.$	4544753.$	4771990.$	5010590.$	5261119.$	5524175.$	5800384.$	6090403.$	6394923.
PROCESSING LABOR		485558.	764715.	802951.	843098.	885253.	929516.	975992.	1024791.	1076031.	1129832.
SELLING EXPENSE		564812.	1119088.	1396201.	1466011.	1539311.	1616277.	1697091.	1781945.	1871043.	1964595.
TOTAL VAR COST	$	2888882.$	5526531.$	6743904.$	7081099.$	7435154.$	7806912.$	8197258.$	8607120.$	9037476.$	9489350.
UNIT VAR COST	$	57.58 $	58.37 $	59.95 $	62.94 $	66.09 $	69.39 $	72.86 $	76.51 $	80.33 $	84.35
PROFIT CONTRI	$	2759242.$	5664352.$	7218105.$	7579010.$	7957961.$	8355859.$	8773652.$	9212334.$	9672951.$	10156597.
ADMIN. OVERHEAD	$	428780.$	450219.$	472730.$	496366.$	521185.$	547244.$	574606.$	603336.$	633503.$	665178.
FACTORY OVERHEAD		1381250.	1450312.	1522828.	1598969.	1678918.	1762864.	1851007.	1943557.	2040735.	2142772.
TOTAL F.C.	$	1810030.$	1900531.$	1995558.$	2095336.$	2200103.$	2310108.$	2425613.$	2546894.$	2674238.$	2807950.
FACILITIES COST	$	0.$	0.$	0.$	0.$	370100.$	0.$	0.$	0.$	0.$	-2975300.
WORKING CAPITAL		362385.	172582.	61206.	64266.	67480.	70854.	74396.	78116.	82022.	-1722462.
INVESTMENT	$	362385.$	172582.$	61206.$	64266.$	437580.$	70854.$	74396.$	78116.$	82022.$	-4697762.
DEPRECIATION	$	2654900.$	2144700.$	1736500.$	1410000.$	1148700.$	959000.$	959000.$	959000.$	959000.$	959000.
AFTER TAX PROFIT	$	610168.$	766168.$	1649598.$	1927663.$	2181054.$	2407051.$	2550093.$	2700288.$	2857992.$	3023581.
A.T. EARNINGS		3265068.	2910868.	3386098.	3337662.	3329754.	3366051.	3509093.	3659288.	3816992.	3982581.
A.T. NET CASH FLOW		2902683.	2738286.	3324892.	3273396.	2892174.	3295197.	3434697.	3581172.	3734970.	8680344.
ACUM NET CASH FLOW	$	-14281.5M $	-11543.2M $	-8218.3M $	-4944.9M $	-2052.7M $	1242.5M $	4677.2M $	8258.3M $	11993.3M $	20673.7M

INTERNAL RATES OF RETURN * * * AT ADJUSTED INPUT VALUES

	80 PCT	90 PCT	100 PCT	110 PCT	120 PCT
UNIT SALES	.099	.126	.150	.173	.195
UNIT PRICE	.065	.110	.150	.187	.222
UNIT VAR COST	.192	.171	.150	.128	.105
TOTAL F.C.	.164	.157	.150	.143	.136
FACILITIES COST	.182	.165	.150	.137	.126

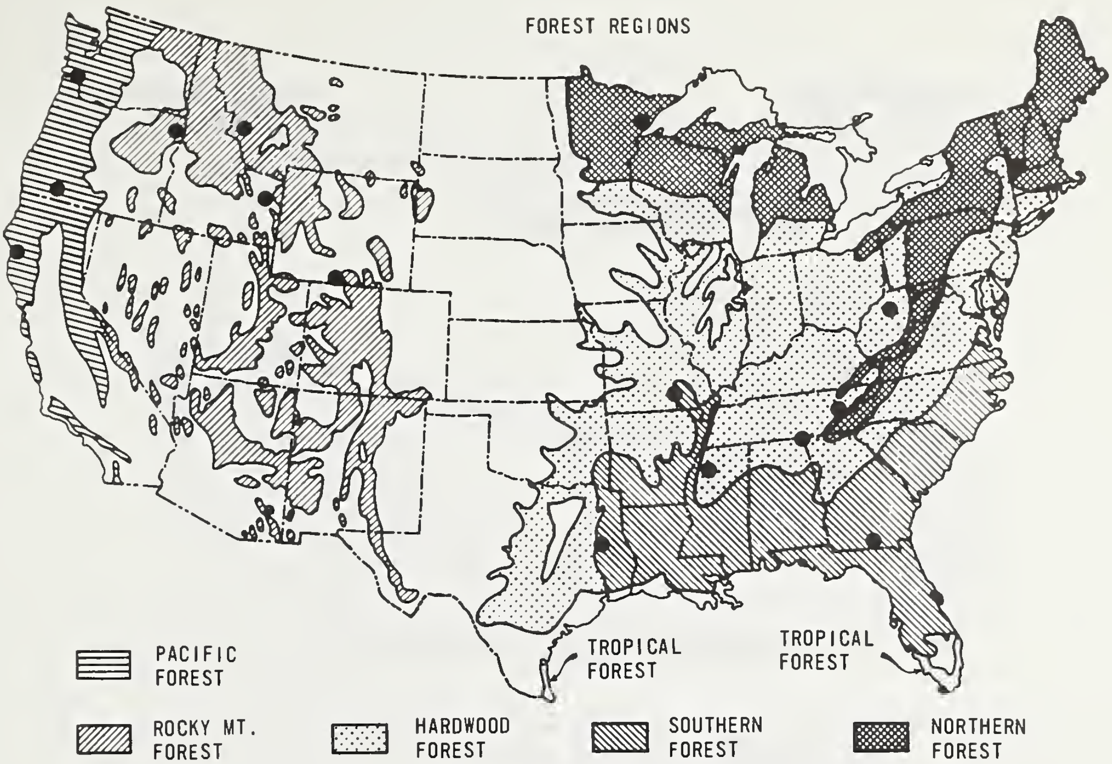

Figure 2.--Sixteen sites in U.S. North and South used for economic assessments of structural flakeboard manufacture.

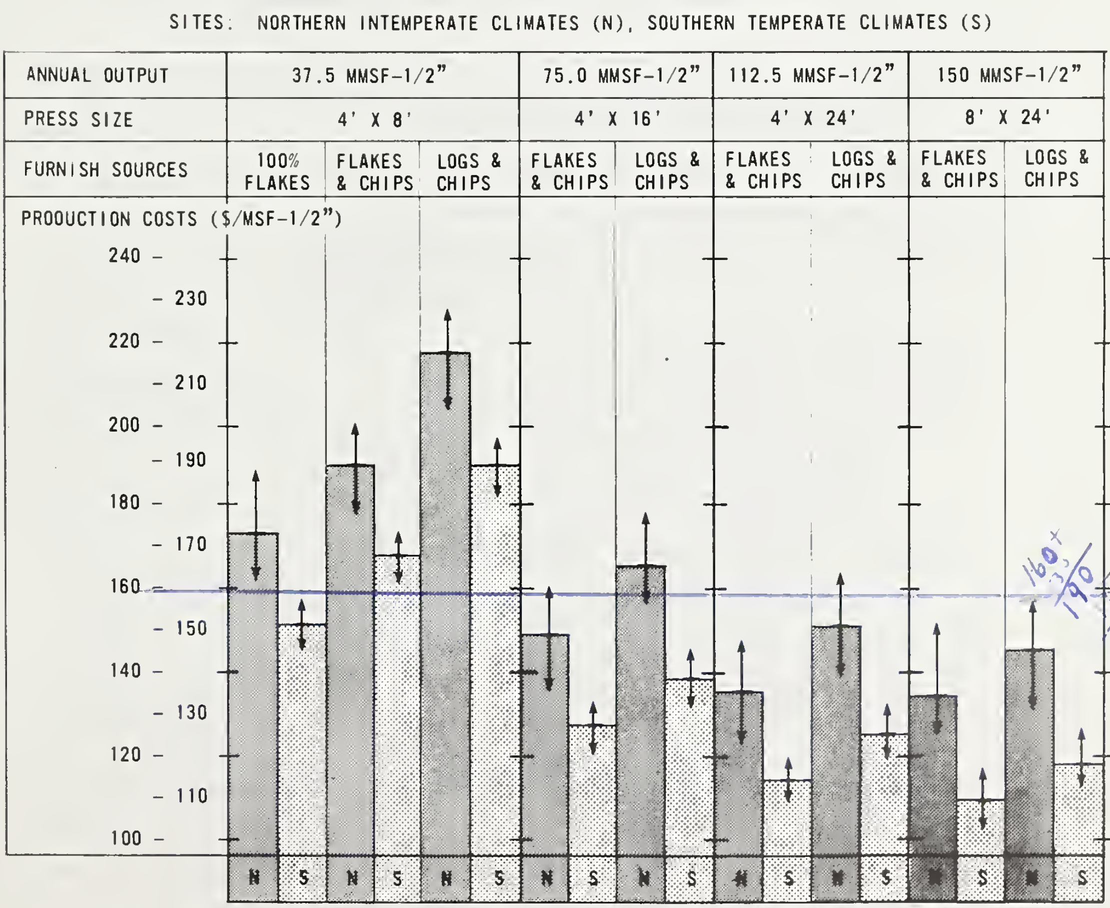

Figure 3.—Average (—), low (V), and high (Λ) production costs, excluding wood costs, 1976 basis.

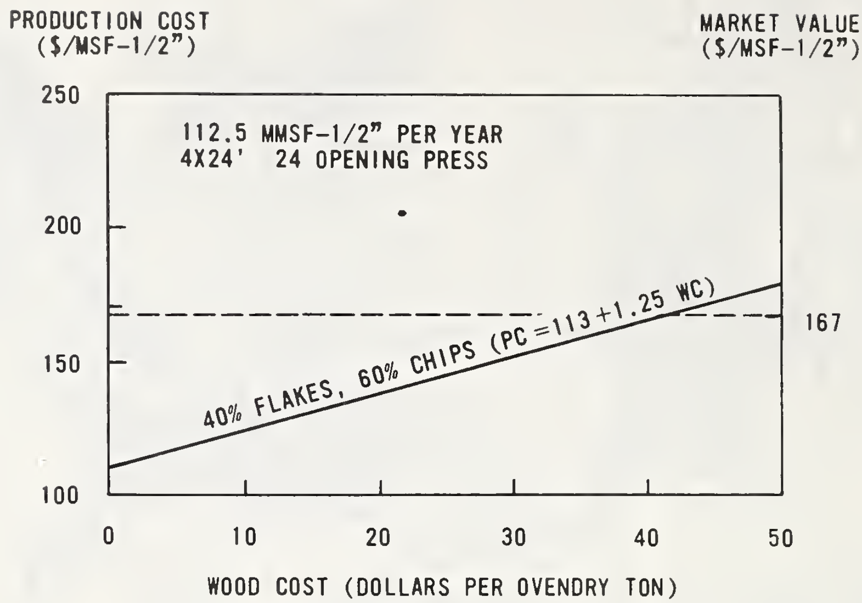

Figure 4.--Production costs, including taxes and profit (15 pct rate of return) and estimated f.o.b. mill market value for structural flakeboard manufacture at Arcata, Calif.

Table 3. Raw material and energy requirements for manufacture of structural flakeboard at an Arcata, Calif. site.

	Requirements Per 1,000 ft^2, 1/2-inch basis
Raw materials and energy:	
Wood (O.D. spec. grav. = .41)[1]	
Pounds of O.D. wood	2,129.8
Pounds of grn. wood	2,768.8
Cubic feet of solid wood	83.3
Resin (pounds of solids)	100.7
Wax (pounds of solids)	20.1
Heat-energy (Btu's)	3.532
Electric power (Kwh)	5.942

[1]Wood requirements expressed in alternate standards of measure.

Table 4.--Raw material and energy requirement costs for manufacture of structural flakeboard at an Arcata, Calif. site--1976 basis.

Requirements	Requirement Costs $/MSF, 1/2" basis (dollars)	
Wood (42¢/ft^3)	35.16	31.00
Resin (5%, 30¢/lb.)	30.21	30.21
Wax (1%, 19¢/lb.)	3.83	3.53
Elec. power (2¢/Kwh)	.12	15.00
Dryer heat (62¢/MMBtu)[1/]	.75	2.00
Process steam (62¢/MMBtu)[1/]	1.74	4.00
Total unit cost	71.81	76.74

[1] Assumes 85% of heat-energy requirements are supplied by wood and bark process residues.

Table 5.--Average production costs for manufacturing structural flakeboard at Arcata, Calif., 1976 basis.

Type of Cost	Production Costs		
	Without wood	With wood[1/]	Difference
	Dollars per thousand square feet, 1/2-inch basis		
Raw materials	36.65	71.81	35.16
Processing labor	6.67	6.67	---
Selling expense	11.26	15.37	4.11
Total variable costs	54.58	93.85	39.27
Overhead	17.07	17.07	---
Depreciation	10.41	10.41	---
Total manufacturing	82.06	121.33	39.27
Taxes (53 pct)	15.01	15.89	.88
Profit (15 pct)	15.50	16.38	.88
Total Production	112.57	153.60	41.03

[1] Wood cost = $33 per ovendry ton.

Table 6.--Production costs for structural flakeboard at northern sites

Production cost ($/MSF-1/2") = a + bX, where a is production cost ($/MSF-1/2") excluding wood cost, and b is coefficient of wood cost per ODT (X) for calculating wood cost per MSF-1/2"

		Annual output--MMSF, 1/2-inch							
		37.5		75.0		112.5		150.0	
Northern Sites	Wood Supply	a	b	a	b	a	b	a	b
St. Anthony, Id.	100% flakes	167.16	1.20						
	40%/60 flakes/chips	180.99	1.20	139.80	1.19	126.55	1.19	124.92	1.17
	40%/60% logs/chips	206.36	1.23	157.49	1.22	141.32	1.22	137.11	1.19
Virginia, Minn.	100% flakes	180.71	1.23						
	40%/60% flakes/chips	195.04	1.23	152.09	1.22	138.40	1.22	136.40	1.19
	40%/60% logs/chips	220.23	1.26	169.47	1.25	153.08	1.25	148.08	1.22
Western Mont.	100% flakes	170.67	1.20						
	40%/60% flakes/chips	184.61	1.20	141.55	1.19	128.45	1.19	126.87	1.17
	40%/60% logs/chips	210.63	1.23	160.31	1.22	144.23	1.22	140.24	1.19
La Grande, Oreg.	100% flakes	172.31	1.23						
	40%/60% flakes/chips	186.32	1.23	143.59	1.22	130.21	1.22	128.55	1.19
	40%/60% logs/chips	212.35	1.26	162.12	1.25	145.75	1.25	141.56	1.22
Medford, Oreg.	100% flakes	169.77	1.26						
	40%/60% flakes/chips	183.35	1.26	141.64	1.24	128.61	1.24	126.88	1.22
	40%/60% logs/chips	208.35	1.29	159.43	1.27	143.48	1.27	139.33	1.25
Southern Vt.	100% flakes	186.64	1.40						
	40%/60% flakes/chips	200.39	1.40	160.16	1.39	147.17	1.39	145.01	1.36
	40%/60% logs/chips	224.31	1.43	176.31	1.42	160.49	1.42	155.83	1.39
Longview, Wash.	100% flakes	169.77	1.26						
	40%/60% flakes/chips	183.35	1.26	141.64	1.24	128.61	1.24	126.88	1.22
	40%/60% logs/chips	208.35	1.29	159.43	1.27	143.48	1.27	139.33	1.25
Northern, W. Va.	100% flakes	171.07	1.40						
	40%/60% flakes/chips	186.43	1.40	148.72	1.39	136.40	1.38	135.16	1.35
	40%/60% logs/chips	209.08	1.43	163.45	1.42	148.49	1.41	144.75	1.39
Laramie, Wyo.	100% flakes	164.32	1.20						
	40%/60% flakes/chips	177.57	1.20	137.99	1.19	125.51	1.19	124.05	1.17
	40%/60% logs/chips	202.07	1.23	155.20	1.22	139.99	1.22	136.19	1.19

Table 7.--Production costs for structural flakeboard at southern sites

Production cost ($/MSF-1/2") = a + bX, where a is production cost ($/MSF-1/2") excluding wood cost, and b is coefficient of wood cost per ODT (X) for calculating wood cost per MSF-1/2"

		Annual output-MMSF, 1/2-inch							
		37.5		75.0		112.5		150.0	
Southern Sites	Wood Supply	a	b	a	b	2	b	a	b
Arcata, Calif.	100% flakes	153.29	1.26						
	40%/60% flakes/chips	166.99	1.26	126.08	1.25	112.57	1.25	109.23	1.22
	40%/60% logs/chips	191.05	1.30	141.36	1.28	124.39	1.28	119.76	1.25
South Central Ga.	100% flakes	149.59	1.40						
	40%/60% flakes/chips	162.77	1.40	125.24	1.38	112.49	1.38	109.45	1.35
	40%/60% logs/chips	183.41	1.43	136.96	1.42	121.00	1.42	116.71	1.39
Cornith, Miss.	100% flakes	151.41	1.40						
	40%/60% flakes/chips	164.41	1.40	128.87	1.38	116.65	1.38	113.72	1.35
	40%/60% logs/chips	184.28	1.43	139.96	1.42	124.69	1.42	120.53	1.38
Southern Mo.	100% flakes	150.59	1.39						
	40%/60% flakes/chips	163.64	1.39	125.75	1.38	113.16	1.38	110.03	1.35
	40%/60% logs/chips	184.03	1.43	137.53	1.41	121.72	1.41	117.36	1.38
Oak Ridge, Tenn.	100%	151.60	1.40						
	40%/60% flakes/chips	164.59	1.40	128.79	1.38	116.51	1.38	113.80	1.35
	40%/60% logs/chips	185.04	1.43	140.28	1.42	124.92	1.42	121.00	1.39
South Eastern Tenn.	100% flakes	146.57	1.40						
	40%/60% flakes/chips	159.75	1.40	122.45	1.39	109.81	1.39	106.87	1.36
	40%/60% logs/chips	182.35	1.43	136.11	1.42	120.27	1.42	115.92	1.39
East Tex.	100% flakes	150.44	1.39						
	40%/60% flakes/chips	163.47	1.39	125.63	1.38	113.05	1.38	109.92	1.35
	40%/60% logs/chips	183.81	1.43	137.39	1.41	121.60	1.41	117.24	1.38

FEASIBILITY OF FLAKEBOARD PRODUCTION IN FOUR SOUTHERN LOCATIONS

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Abstract

Flakeboard manufactured from a species mix of 60-percent dense hardwoods and 40-percent soft hardwoods or southern pine can be manufactured profitably in southern plants whose annual capacities range from 37.5 to 150-million square feet (1/2-inch basis). The 1/2-inch flakeboards will weigh about 50 pounds per cubic foot and can be delivered to retail yards in the Midwest, South, and East at prices $20 to $90 lower per 1,000 square feet than the 1977 average sale price of 1/2-inch 3-ply CD exterior southern pine plywood. Plants will operate most profitably on residual flakes from other manufacturing operations; wood supplied as flakes and chips will yield more profit than that supplied as chips and roundwood. Large plants will be more profitable than small plants. Of plant locations studied, south Georgia and the Arkansas-Missouri border have the highest profit potential; plants on the Texas-Louisiana border and in West Virginia appear slightly less promising. However, even the poorest location indicates after-tax profits in excess of 15 percent on entire capital requirement while underselling 1/2-inch southern pine plywood by $20 per thousand square feet (based on 1977 plywood prices). Total capital requirements range from $8.2 to $28.9 million, depending on plant capacity, type of wood processed, and plant location.

By the year 2000 about half of all softwood harvested in the United States will be southern pine--largely committed to production of lumber, plywood, poles, fiberboard, particleboard, and pulp. Little surplus volume will be available to supply a major new commodity market such as that anticipated for structural exterior flakeboard.

There is, however, a major under-utilized wood resource in the South--hardwoods growing on southern pine sites. On these sites, about 0.8 cubic foot of hardwoods are present for every cubic foot of southern pine. Twenty-two species account for over 90 percent of the hardwood volume. Eleven of the 22 species are oaks, and they comprise nearly half of the volume. Sweetgum and hickory are the next leading species. About half the volume is in trees 5 to 11.9 inches in d.b.h. and averaging 40 to 70 years of age. The remainder is about equally divided between trees 12 to 14.9 inches d.b.h. and trees 15 inches or larger (Murphy and Knight 1974). With the exceptions of yellow-poplar, sweetbay, sweetgum, and red maple (the soft hardwoods) all exceed 0.5 specific gravity (Table 1).

Species mix varies with location, but throughout the South (except in northern Arkansas and southern Missouri) a mix of approximately 60-percent hard hardwoods and 40-percent softwoods and soft hardwoods is available. From such a mix, a structural flakeboard can be fabricated to a shipping weight of 47 to 50 pounds per cubic foot (Hse et al. 1975, and Price 1977).

In northern Arkansas and southern Missouri less than 10 percent of the hardwood resource is soft hardwoods and southern pine is in limited supply. Oaks and hickories, however, are plentiful. Flakeboards containing mostly oak and hickory may have shipping weights of 50 to 54 pounds per cubic foot, slightly higher than that of boards made with a mix containing softwoods and soft hardwoods. In this analysis, flakeboards from all southern locations have been assigned a shipping weight of 2,083 pounds per 1,000 square feet of 1/2-inch board, or 50 pounds per cubic foot.

The hardwood species on pine sites are spread across the 12 southern states (Table 2). Large volumes also grow in Missouri and West Virginia. Their distribution in the 12 southern states is shown in maps provided by Christopher et al. (1976).

The foregoing summarizes hardwood survey data specific to southern pine sites. Additional state and regional data are periodically available, however, for the hardwood resource on all site classes. Readers interested in the most current survey data should direct their queries to the Southern and Southeastern Forest Experiment Stations of the U.S. Forest Service. A sampling of recent references containing data on the 12-State southern region plus Missouri and West Virginia follows on page 153.

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[1]Steve Moore, Wood Markets Inc., Portland, Oregon, provided data on average 1977 prices for plywood and December 1977 rail rates from producing areas to markets.

[2]The Traffic Department of the Tennessee Valley Authority, Norris, Tennessee, provided suggestions on plant sites and data on rail and truck freight rates from proposed flakeboard plant sites to market cities..

Table 1. - SPECIFIC GRAVITY, MOISTURE CONTENT, AND GREEN WOOD WEIGHT OF STEMWOOD FROM 6-INCH HARDWOODS ON SOUTHERN PINE SITES[a]

Species	Percent of total volume[b]	Stemwood specific gravity[c]	Stemwood moisture content[d]	Weight of bark-free green stemwood
			(Percent)	(Pounds/cu.ft.)
Ash, green	0.9	0.561	47.4	51.6
Ash, white		.582	47.5	53.6
Elm, American	1.4	.536	75.5	58.7
Elm, winged		.623	65.6	64.4
Hackberry	.1	.525	72.6	56.5
Hickory, true	8.5	.643	51.5	60.8
Maple, red	3.6	.496	69.9	52.6
Oak, black	4.0	.620	69.2	65.5
Oak, blackjack	<.1	.638	74.2	69.4
Oak, cherrybark	1.2	.633	66.6	65.8
Oak, chestnut	4.2	e	e	e
Oak, laurel	1.4	.582	74.4	63.3
Oak, northern red	2.4	.605	69.7	64.1
Oak, post	7.0	.659	65.6	68.1
Oak, scarlet	3.6	.622	69.4	65.7
Oak, Shumard	.2	.625	69.1	65.9
Oak, southern red	8.1	.609	70.1	64.6
Oak, water	4.7	.587	73.6	63.6
Oak, white	12.3	.665	61.9	67.2
Sweetbay	.6	.437	100.8	54.8
Sweetgum	13.2	.453	120.4	62.3
Tupelo, black	5.5	.500	90.0	59.3
Yellow-poplar	7.0	.395	111.7	52.2
Other hardwoods	10.1	--	--	--
	100.0			

[a]Data from Manwiller (1978).

[b]Data from Christoper et al. (1976).

[c]Basis of ovendry weight and volume when green.

[d]Dry weight basis.

[e]Data not available.

Table 2. - VOLUMES OF HARDWOODS ON SOUTHERN PINE SITES BY STATE[a]

Species	Alabama	Arkansas	Florida	Georgia	Louisiana	Mississippi	North Carolina	Oklahoma	South Carolina	Tennessee	Texas	Virginia
	(Million cubic feet)											
Ash, sp.	53	50	2	45	42	29	42	5	42	42	33	56
Elm, sp.	68	102	4	80	47	82	63	18	71	26	64	43
Hackberry, sp.	8	5	1	2	3	4	6	1	9	4	13	1
Hickory, sp.	850	518	37	501	197	356	422	88	185	492	155	372
Maple, red	126	41	23	244	51	53	502	2	153	147	25	384
Oak, black	255	353	--	188	19	94	219	53	78	333	20	337
cherrybark	43	109	--	12	110	120	40	1	52	6	69	17
chestnut	285	--	--	224	--	3	300	--	35	571	--	685
laurel	95	--	146	254	42	12	--	--	113	--	18	3
northern red	105	221	--	148	--	6	150	12	55	208	--	264
post	381	801	15	252	307	453	261	226	132	139	405	72
scarlet	166	2	--	247	--	39	420	--	94	321	--	510
Shumard	25	15	1	12	3	46	--	4	6	2	6	--
southern red	602	589	49	418	446	568	357	35	170	132	343	285
water	379	112	104	459	254	217	293	6	268	1	219	20
white	633	893	8	573	283	438	1,022	62	287	530	180	1,149
Sweetbay	82	1	60	37	36	63	7	--	2	--	10	2
Sweetgum	950	611	93	1,055	690	531	804	32	636	53	554	499
Tupelo, black	323	216	158	575	154	233	298	18	296	111	124	204
Yellow-poplar	419	1	14	616	10	122	946	--	210	278	--	805
Other hardwoods	609	286	363	658	391	358	686	70	464	328	355	410
Total	6,456	4,926	1,078	6,600	3,085	3,827	6,838	633	3,358	3,724	2,593	6,118

[a]Christoper et al. 1976. Volumes of bark-free wood in trees 5 inches and larger in dbh outside bark to a 4-inch top measured outside bark.

State and reference	Title
Alabama	
Beltz (1975a)	Alabama's timber resources updated, 1975
Hedlund and Earles (1973)	Forest statistics for Alabama counties
Murphy (1973)	Alabama forests: trends and prospects
Arkansas	
Beltz (1975b)	Arkansas's timber resources updated, 1975
Hedlund and Earles (1970)	Forest statistics for Arkansas counties
Van Sickle (1970)	Arkansas forest resource patterns
Georgia	
Morris and Steinbeck (1974)	Georgia's timber resources
Florida	
Knight and McClure (1971)	Florida's timber, 1970
Louisiana	
Bertelson (1974)	Louisiana forest industries, 1973

State and reference	Title
Earles (1975)	Forest statistics for Louisiana parishes
Maddocks (1976)	Hardwoods & wildlife--here today, here tomorrow. Part I: manage the hardwoods.
Murphy (1975)	Louisiana forests: status & outlook
Mississippi	
Beltz and Christopher (1970)	Computer program for updating timber resource statistics by county, with tables for Mississippi
Hedlund and Earles (1969)	Forest statistics for Mississippi counties
Van Sickle and Van Hooser (1969)	Forest resources of Mississippi
Missouri	
Essex and Spencer (1974)	Timber resources of Missouri's eastern Ozarks--'72
Hahn and Vasilevsky (1975)	Timber resources of Missouri's Prairie region
Ostrom (1974)	Timber volume in Missouri counties
North Carolina	
Cost (1975)	Forest statistics for the Mountain Region of North Carolina, 1974
Knight (1975a)	A preview of "North Carolina's timber, 1974"
Knight (1975b)	North Carolina's timberland acreage is declining
Knight and McClure (1966)	North Carolina's timber
South Carolina	
Knight and McClure (1969)	South Carolina's timber, 1968
Oklahoma	
Murphy (1977)	East Oklahoma forests: trends and outlook
Earles (1976a)	Forest statistics for east Oklahoma counties
Tennessee	
Hedlund and Earles (1971)	Forest statistics for Tennessee
Murphy (1972)	Forest resources of Tennessee
Texas	
Bertelson (1975a)	East Texas forest industries, 1974
Earles (1976b)	Forest statistics for east Texas piney woods counties
Murphy (1976)	East Texas forests: status and trends
Virginia	
Knight and McClure (1967)	Virginia's timber, 1966
West Virginia	
Ferguson (1964)	The timber resources of West Virginia

Southwide data are reported in the following publications:

Reference	Title
Bellamy (1972)	Southern pulpwood production, 1971
Bellamy (1974)	Southerm pulpwood production, 1973
Beltz (1972)	Midsouth pulpwood movement
Beltz and Bertelson	Timber resource statistics for Midsouth counties, 1971
Bertelson (1973)	Southern pulpwood production, 1972
Bertelson (1975b)	Southern pulpwood production, 1974
Cruikshank and McCormack (1956)	The distribution and volume of hickory timber
Earles (1973)	Forest area statistics for Midsouth counties
Hair (1966)	Projected demands for hardwood veneer emphasize research-management needs

Reference	Title
Harold (1976)	TVA is looking ahead at veneer timber opportunities
Hedlund and Knight (1969)	Hardwood distribution maps for the South
Hertzler (1951)	Southern hardwoods for veneer and plywood
Murphy[3]	The timber resource of the Midsouth
Ostermeier (1975)	The South's forest products industries: a major industrial sector
Quigley (1971)	The supply and demand situation for oak timber
Siegel (1963)	The changing hardwood lumber industry
Sternitzke (1973)	The South's timber resources: status and trends
Sternitzke (1974)	Eastern hardwood resources: trends and prospects
Sternitzke (1975)	Shifting hardwood trends in the South
Sternitzke (1976)	Impact of changing land use on delta hardwood forests

These numerous publications verify that hardwood resources are adequate for flakeboard manufacturing operations at many southern locations. Optimum sites at which to manufacture flakeboard are not solely determined by wood supply, however. Price and freight structure in Eastern, Southern, and Midwestern plywood markets are also major factors.

Plywood Price and Freight Structure

Flakeboard sheathing will compete in price and function with CD exterior flakeboard sheathing made from Douglas-fir and southern pine. To enter the market, 1/2-inch flakeboard probably must undersell 3-ply southern pine, the most economical 1/2-inch plywood sheathing. Because flakeboard sheathing is heavier and harder to nail than plywood sheathing of the same thickness, it seems likely that a price differential will be needed to induce carpenters to use the heavier product. It might be noted, however, that flakeboard weighs no more than gypsum board which carpenters handle routinely without undue difficulty. Some manufacturers contemplating flakeboard production feel that floor underlayment provides easiest market entry, because the heavy flakeboard panels are more easily handled at floor level than on roofs.

Mill prices and delivered prices for sheathing are dependent on the cost of transportation to market. For example, based on December 1977 freight rates, east Texas mills undersold West Coast mills in all eastern markets studied; moreover, the east Texas plywood mills received (FOB mill) about $11 more per thousand square feet of 1/2-inch 3-ply sheathing than did West Coast mills (Tables 3 and 4).

Plywood mills throughout the South generally obtain FOB mill prices that enable them to meet delivered prices by east Texas mills, i.e., all the southern mills deliver plywood to market destinations at about the same price (Table 4, right-hand column).

Plant Location and Freight Costs

As previously noted, mill prices for sheathing are dependent on the cost of transportation to market (Tables 3 and 4).

Because the wood resource for flakeboard is distributed throughout the South, many locations can advantageously serve large markets. Four such locations, with associated markets are listed on page 158.

The towns named as possible mill sites are not necessarily optimum; they served, however, as locations from which to base transportation charges to markets. Rail transport costs to representative markets range from about $10 to over $25 per thousand square feet of 1/2-inch flakeboard (Table 5). Rail freight from Crockett, Texas, to Kansas City seems disproportionately high ($25.88); lower transport costs could perhaps be achieved from a different location in the general area.

[3] Murphy, P.A. The timber resource of the Midsouth. Paper presented at the Mid-South Section meeting to the For. Prod. Res. Soc. at Jackson, Miss., Oct. 13-14, 1976. 23 p.

Table 3. - PRICE PAID BY RETAILERS AT EIGHT LOCATIONS FOR 1/2-INCH CD EXTERIOR DOUGLAS-FIR 3-PLY SHEATHING PLYWOOD, BASED ON AVERAGE 1977 MILL PRICES AND DECEMBER 1977 FREIGHT RATES

Retail Location	Rail freight per CWT from Portland[a]	Freight per thousand square feet[b]	FOB West-Coast mill price[c,d]	Price paid by retailer for sheathing
		(Dollars)		
Houston	2.63	40.11	211	251
Kansas City	2.39	36.45	211	247
St. Louis	2.63	40.11	211	251
Chicago	2.66	40.57	211	252
Tampa	3.20	48.80	211	260
Mobile	2.99	45.60	211	257
Pittsburg	3.16	48.19	211	259
New York	3.20	48.80	211	260

[a]85,000-pound rate on first four destinations and 75,000-pound minimum on last four destinations.

[b]Based on 1,525 pounds per 1,000 square feet.

[c]Average for 1977; from this price, the retailer got only a 2% cash discount for payment in 10 days.

[d]4- and 5-ply sheathing sells FOB mill at a price about $9 higher than these values for 3-ply.

Table 4. - PRICE PAID BY RETAILERS AT EIGHT LOCATIONS FOR 1/2-INCH CD EXTERIOR SOUTHERN PINE 3-PLY SHEATHING PLYWOOD, BASED ON AVERAGE 1977 EAST TEXAS MILL PRICES AND DECEMBER 1977 FREIGHT RATES

Retail location	Rail freight per CWT from east Texas[a]	Freight per thousand square feet[b]	FOB east Texas mill price[c]	Price paid by retailer for sheathing
		(Dollars)		
Houston	0.44	6.71	222	229
Kansas City	1.05	16.01	222	238
St. Louis	1.04	15.86	222	238
Chicago	1.30	19.83	222	242
Tampa	1.35	20.59	222	243
Mobile	.86	13.12	222	235
Pittsburh	1.75	26.69	222	249
New York	2.13	32.48	222	254

[a]Based on average shipment weight of 115,000 pounds per car.

[b]Based on 1,525 pounds per 1,000 square feet.

[c]Average for 1977; from this price the retailer got only a 2% cash discount for payment in 10 days.

Plant location	Primary market	Secondary market
Texas-Louisiana border (e.g., Crockett, TX)	Dallas-Ft. Worth Houston Waco San Antonio Austin Abilene	St. Louis Kansas City Wichita Topeka Oklahoma City Tulsa
Arkansas-Missouri border (e.g., Hoxie, Ark.)	St. Louis Kansas City	Chicago Indianapolis Cincinnati Topeka
South Georgia (e.g., Waycross)	Savannah Atlanta Jacksonville Tampa Miami Gainsville Orlando Tallahassee	Mobile Birmingham Huntsville
Northern West Virginia (e.g., Grafton)	Columbus Cleveland Washington, D.C. Pittsburg Wheeling	Boston New York Buffalo

Table 5. - POTENTIAL MILL-MARKET LOCATION, FOB MILL SALES PRICES, FREIGHT COSTS, AND ESTIMATED DELIVERED SALES PRICES FOR 1/2-INCH STRUCTURAL EXTERIOR FLAKEBOARD SHEATHING

			Flakeboard freight to[a]		Price delivered to retailer[b]		Estimated flakeboard sales price FOB mill[c]	
Mill location	Major market	Extended market	Major market	Extended market	Major market	Extended market	Major market	Extended market
			(Dollars per 1,000 square feet)					
Crockett, Texas	Houston	Kansas City	9.17	25.88	209	218	200	192
Hoxie, Arkansas	St. Louis	Chicago	11.71	20.78	218	222	206	201
Waycross, Georgia	Tampa	Mobile	10.14	15.62	223	215	213	199
Grafton, West Virginia	Pitts-burg	New York	10.55	18.33	229	234	218	216

[a]Based on 90,000-pound car containing 43,207 square feet of 1/2-inch flakeboard with shipping weight of 50 pounds per cubic foot.

[b]Priced to undersell 1/2-inch 3-ply CD exterior southern pine plywood sheathing by $20 per thousand square feet, based on 1977 average plywood prices.

[c]From this price the retailer will get only a 2-percent discount for payment of invoice within 10 days.

Approximate costs to truck 1/2-inch flakeboard from these locations are:

Origin and destination	Minimum load 24,000 pounds	Minimum load 30,000 pounds
	(Dollars per 1,000 square feet)	
Grafton, West Virginia		
Pittsburg	28.33	27.29
New York	43.12	41.24
Waycross, Georgia		
Tampa	--	29.16
Mobile	--	36.66
Hoxie, Arkansas		
St. Louis	30.00	--
Chicago	47.91	--
Crockett, Texas		
Houston	--	21.45
Kansas City	61.03	--

Estimated Sales Price Obtainable

To predict FOB mill prices for 1/2-inch flakeboard sheathing, a delivered price at which the retailer will switch from plywood to flakeboard must first be estimated. Because flakeboard from southern hardwoods is heavier and harder to nail than plywood, it will probably have to be offered at a lower price (perhaps $20 per thousand square feet less) than plywood. On the basis of 1977 prices for plywood this assumption results in FOB mill prices in the range from $192 to $218 per thousand square feet depending on mill and market locations (Table 5).

It is recognized that plywood prices were at record high levels in 1977, but it seems doubtful that they will be appreciably lower in the years ahead. It is worth noting, however, that during the low market of 1974, FOB mill prices for 1/2-inch plywood were nearly $100 per thousand square feet lower than the 1977 average.

Production Cost

Total mill price must include wood costs and production costs; production costs as defined in Section 3.2 include the costs of raw material (except wood), manufacturing, selling, overhead, discounts, commissions, and a profit on the entire capital requirement sufficient to yield about 15-percent return after State and Federal taxes.

These production costs vary according to plant location, plant capacity, and form of wood entering the plant (i.e., roundwood requiring debarking or residual bark-free chips or flakes residual from other manufacturing operations). The relationships among these variables are mathematically expressed in Table 6 and illustrated in Figures 1 through 4.

Capital Requirements

Capital requirements during the first 10 years of plant life will vary with location, type of wood, and plant capacity, but can be summarized as follows:

Annual plant capacity of 1/2-inch flakeboard (million square feet) and type of wood	Total capital requirement including operating capital
	(Million dollars)
37.5	
Flakes	8.2 - 8.7
Flakes and chips	9.4 - 9.9
Chips and roundwood	11.5 - 12.2
75.0	
Flakes and chips	13.4 - 14.2
Chips and roundwood	15.8 - 17.1
112.5	
Flakes and chips	17.2 - 18.3
Chips and roundwood	19.9 - 22.1
150.0	
Flakes and chips	22.7 - 24.9
Chips and roundwood	25.9 - 28.9

For all plants, capital costs were estimated to be least in the Georgia location, and most in West Virginia.

Table 6. - TOTAL MILL COSTS, INCLUDING WOOD, DISCOUNTS AND COMMISSIONS, AND 15 PERCENT AFTER-TAX PROFIT, TO MANUFACTURE A THOUSAND SQUARE FEET OF 1/2-INCH STRUCTURAL EXTERIOR FLAKEBOARD FROM MIXED SOUTHERN SPECIES IN MILLS OF FOUR CAPACITIES, USING THREE TYPES OF FURNISH, IN FOUR GEOGRAPHICAL LOCATIONS. COSTS ARE EXPRESSED IN TERMS OF WOOD COST PER DRY TON (X) IN REGRESSION EQUATIONS OF THE FORM: TOTAL COST = A + BX

Mill location and form of wood used	Intercept A	Slope B	Estimated[a] wood cost X	Total mill cost	Estimated achievable sales price FOB mill[b]
			($/dry ton)	($/thousand square feet)	
37.5 MILLION SQUARE FEET ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes[c]	150.44	1.39	16	173	192
Flakes and chips[d]	163.47	1.39	16	186	to
Roundwood and chips[e]	183.81	1.43	16	207	200
Arkansas-Missouri border					
Flakes	150.59	1.39	18	176	201
Flakes and chips	163.64	1.39	18	189	to
Roundwood and chips	184.03	1.43	16	207	206
South Georgia					
Flakes	153.29	1.26	18	176	199
Flakes and chips	166.99	1.26	18	190	to
Roundwood and chips	191.05	1.30	20	217	213
West Virginia					
Flakes	171.07	1.40	18	196	216
Flakes and chips	186.43	1.40	18	212	to
Roundwood and chips	209.08	1.43	19	236	218
75 MILLION SQUARE FEET ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	125.63	1.38	16	148	192 to
Chips and roundwood	137.39	1.41	16	160	200
Arkansas-Missouri border					
Flakes and chips	125.75	1.38	18	151	200 to
Roundwood and chips	137.53	1.41	16	160	206
South Georgia					
Flakes and chips	125.24	1.38	18	150	199 to
Roundwood and chips	136.96	1.42	20	165	213
West Virginia					
Flakes and chips	148.72	1.39	18	174	216 to
Roundwood and chips	163.45	1.42	19	190	218
112.5 MILLION SQUARE FEET ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	113.05	1.38	16	135	192 to
Roundwood and chips	121.60	1.41	16	144	200
Arkansas-Missouri border					
Flakes and chips	113.16	1.38	18	138	200 to
Roundwood and chips	121.72	1.41	16	144	206
South Georgia					
Flakes and chips	112.49	1.38	18	137	199 to
Roundwood and chips	121.00	1.42	20	149	213
West Virginia					
Flakes and chips	136.40	1.38	18	161	216 to
Roundwood and chips	148.49	1.41	19	175	218

Table 6. - Continued

Mill location and form of wood used	Intercept A	Slope B	Estimated[a] wood cost X	Total mill cost	Estimated achievable sales price FOB mill[b]
150 MILLION SQUARE FEET ANNUAL CAPACITY, 1/2-INCH BASIS					
Texas-Louisiana border					
Flakes and chips	109.92	1.35	16	132	192 to
Roundwood and chips	117.24	1.38	16	139	200
Arkansas-Missouri border					
Flakes and chips	110.03	1.35	18	134	201 to
Roundwood and chips	117.36	1.38	16	139	206
South Georgia					
Flakes and chips	109.45	1.35	18	134	199 to
Roundwood and chips	116.71	1.39	20	145	213
West Virginia					
Flakes and chips	135.16	1.35	18	159	216 to
Roundwood and chips	144.75	1.39	19	171	218

[a]Based on 1976 regional wood prices and assuming that flakes residual from other manufacturing operations are priced the same as residual bark-free pulp chips; assumes 60 percent dense hardwoods and 40 percent soft hardwoods or softwoods.

[b]From Table 5.

[c]100 percent flakes.

[d]40 percent flakes and 60 percent chips.

[e]40 percent chips and 60 percent barky roundwood.

Conclusions and Discussion

Except for mills with smallest annual capacity using roundwood, all flakeboard plants could be profitable at all locations using any of the forms of wood supply. Large plants will be more profitable than small plants if wood costs are the same for both.

The amount by which estimated FOB mill sales price exceeds (or falls short of) estimated mill cost, including 15-percent after tax profit on entire capital requirement, varies with location as shown on page 162.

These amounts are based on 1976 wood costs. For each dollar per ovendry ton that current wood costs exceed those in Table 6, amounts will be reduced by $1.26 to $1.43 per thousand square feet. For example, if 1978 wood costs are $4/dry ton higher than values in Table 6, spreads will be reduced $5 to $6 per thousand square feet.

Assuming flakes can be purchased for the same price as chips, plants will operate most profitably on residual flakes. A mixture of flakes and chips will yield more profit than a mixture of chips and roundwood.

All locations should accommodate profitable mills, but the south Georgia and Arkansas-Missouri border locations appear to offer the greatest profit potential. Although West Virginia is adjacent to markets that should pay most for sheathing (because of high freight costs from competing regions), manufacturing costs are estimated to be somewhat higher than in other southern locations, and estimated profit is therefore lower.

Best board properties will be achieved through use of precisely manufactured flakes. With present knowledge, precisely manufactured flakes cannot be cut from ordinary pulp chips or even from maxi-chips; flakes derived from such chips must therefore be used in panel cores and not in faces.

As previously explained, a small-capacity plant capable of manufacturing 37.5 million square feet of 1/2-inch flakeboard might be supplied completely by residual flakes from a pallet, crosstie, post, and stud mill using a 9-foot shaping-lathe headrig operating three

Mill location and annual capacity (million square feet)	Form of wood entering mill		
	Flakes	Flakes and chips	Chips and roundwood
	(Dollars per 1,000 square feet, 1/2-inch basis)		
Texas-Louisiana border			
37.5	23	10	(11)
75.0	--	48	36
112.5	--	61	52
150.0	--	64	57
Arkansas-Missouri border			
37.5	28	15	(3)
75.0	--	53	44
112.5	--	66	60
150.0	--	70	65
South Georgia			
37.5	30	16	(11)
75.0	--	56	41
112.5	--	69	57
150.0	--	72	61
West Virginia			
37.5	21	5	(19)
75.0	--	43	27
112.5	--	56	42
150.0	--	58	46

shifts (see also: Howe and Koch 1976; Koch 1975; 1976; Koch and Caughey 1978).

Plants of all sizes could be supplied with such flakes for use in faces, supplemented with maxi-chips to be ring-flaked and used in cores. Alternatively, roundwood could be processed through disk or drum flakers to yield face flakes, and maxi-chips could be ring-flaked for cores.

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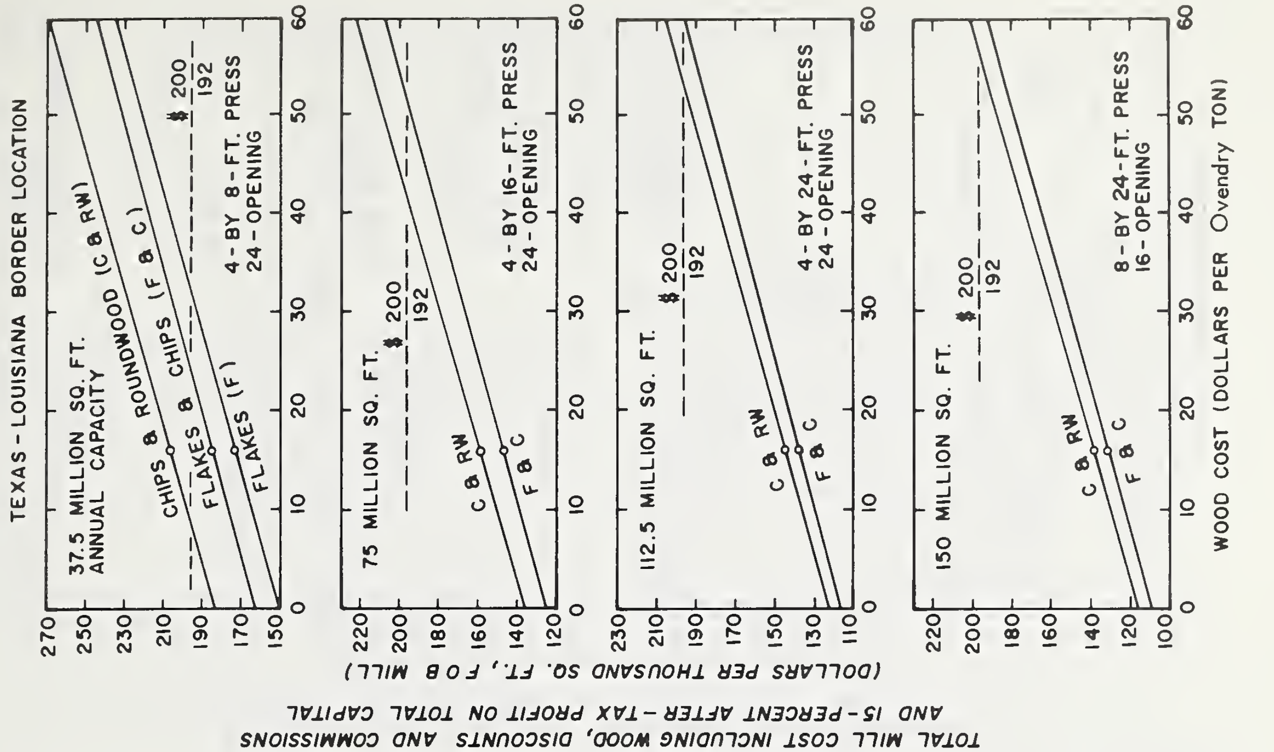

Figure 1.--Total manufacturing cost of 1/2-inch structural flakeboard at a Texas-Lousiana border location related to wood cost, plant capacity, and form of wood. A 1976 wood cost estimate is indicated by the single data point on each graph line. The horizontal dashed line indicates probable FOB mill price obtainable in primary and extended market areas based on average 1977 plywood prices (see tables 4, 5, and 6) and December 1977 rail freight rates Wood costs are for a mix of 60 percent dense hardwoods and 40 percent soft hardwoods or softwood.

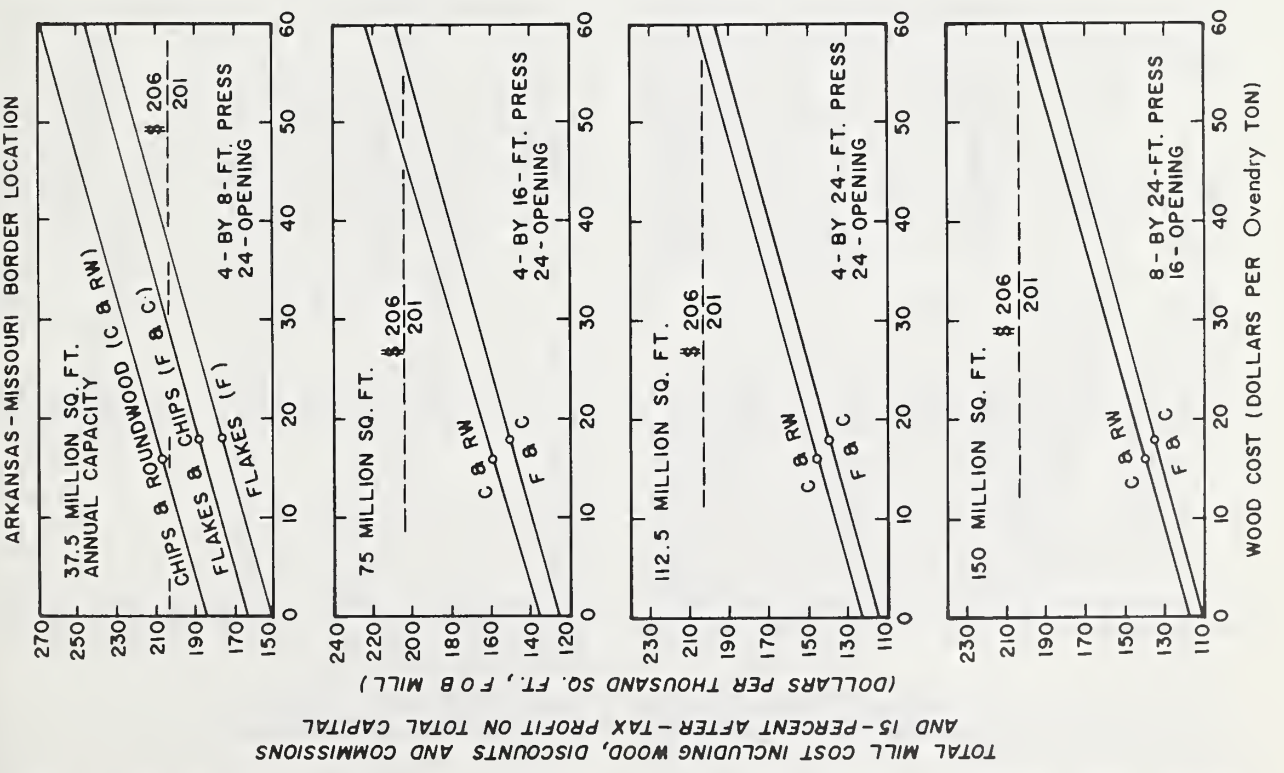

Figure 2.--Total manufacturing cost of 1/2-inch structural flakeboard at an Arkansas-Missouri border location related to wood cost, plant capacity, and form of wood. A 1976 wood cost estimate is indicated by the single data point on each graph line. The horizontal dashed line indicates probable FOB mill price obtainable in primary and extended market areas based on average 1977 plywood prices (see tables 4, 5, and 6) and December 1977 rail freight rates. Wood costs are for a mix of 60 percent dense hardwoods and 40 percent soft hardwoods or softwood.

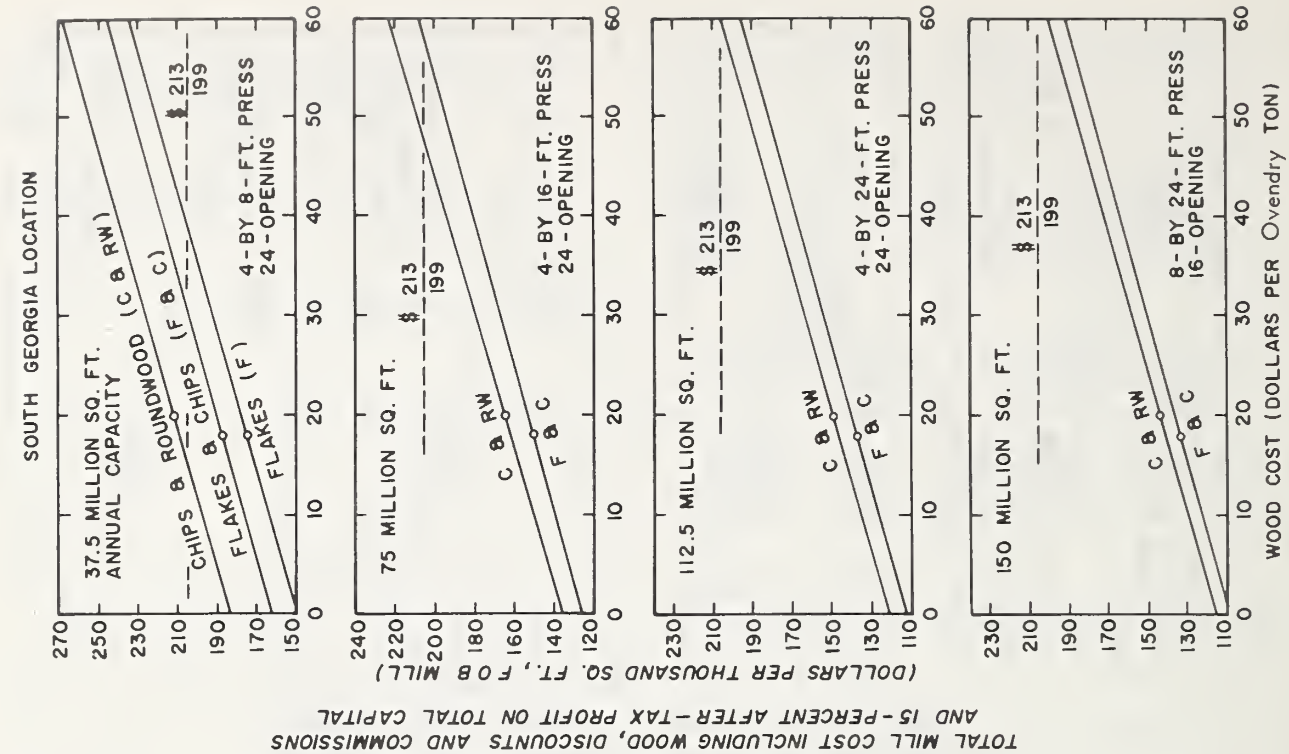

Figure 3.--Total manufacturing cost of 1/2-inch structural flakeboard at a south Georgia location related to wood cost, plant capacity, and form of wood. A 1976 wood cost estimate is indicated by the single data point on each graph line. The horizontal dashed line indicates probable FOB mill price obtainable in primary and extended market areas based on average 1977 plywood prices (see tables 4, 5, and 6) and December 1977 rail freight rates. Wood costs are for a mix of 60 percent dense hardwoods and 40 percent soft hardwoods or softwood.

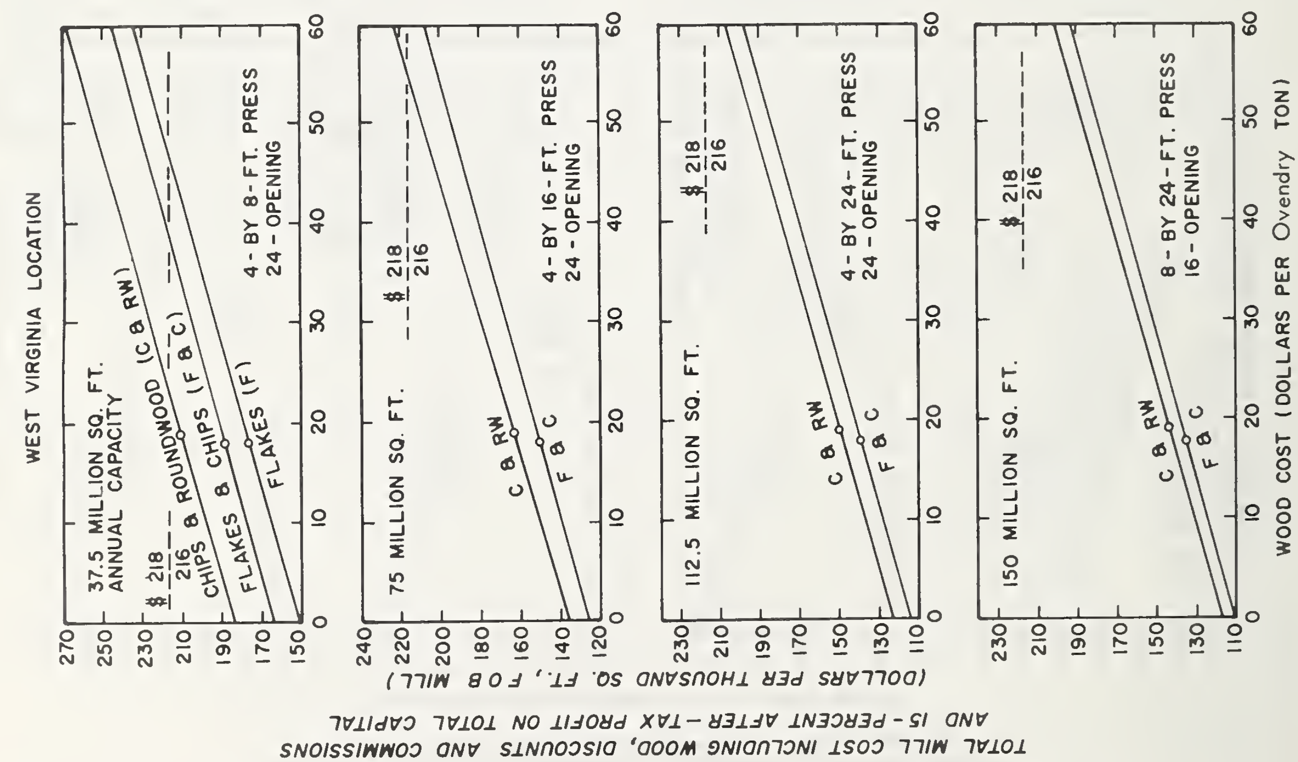

Figure 4.--Total manufacturing cost of 1/2-inch structural flakeboard at a West Virginia location related to wood cost, plant capacity, and form of wood. A 1976 wood cost estimate is indicated by the single data point on each graph line. The horizontal dashed line indicates probable FOB mill price obtainable in primary and extended market areas based on average 1977 plywood prices (see tables 4, 5, and 6) and December 1977 rail freight rates. Wood costs are for a mix of 60 percent dense hardwoods and 40 percent soft hardwoods or softwood.

FEASIBILITY OF STRUCTURAL FLAKEBOARD MANUFACTURE VIRGINIA, MINNESOTA

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Abstract

Virginia, Minnesota, was chosen as a potential flakeboard plant site because of an abundant underutilized aspen resource in the area. Volumes of forest and plant residues from harvesting and processing are not large. Nearly 80 percent of timber products output is pulpwood, and much of the sawlog output comes from small saw-timber trees. Two thirds of the 7.5 million acres of commercial forest land in a six county area surrounding Virginia is in public ownership and these lands are the main source of supply. Pulp chips are delivered to area mills for $21.00 to $25.50 per oven dry ton, roundwood rough pulpwood for approximately $18 per oven dry ton. The closest major market area is Minneapolis-St. Paul.

Introduction

When given the task of assessing the feasibility of a structural flakeboard plant in the North Central region, we chose the location of Virginia, Minnesota primarily because of the underutilized aspen forest resource in the area.

Virginia is located approximately 200 miles north of Minneapolis-St. Paul and 60 miles northwest of Duluth, where our research work unit is located. It is in the east central part of what is known as the 18 northern forested counties of Minnesota, an area that contains 82 percent of the commercial forest land in the state. Our resource assessment covers a 6-county area within an approximate 75-mile radius of Virginia, Fig. 1.

Current major wood use centers are located in International Falls on the Canadian border, Bemidji, Grand Rapids, Cloquet, and Duluth.

The area's economy is based largely on three industries: Taconite, tourism, and timber. Virginia is in the heart of the famous Mesabi Iron Range, and close to the famous Boundary Waters Canoe Area and the recently created Voyageurs National Park. Timbering peaked in Minnesota in 1899, and in the Duluth area in 1903. The Virginia area probably experienced the waning moments of big time lumbering in the Lake States following World War I. It was during this period that extensive timber cutting and subsequent slash fires gave rise to the large acreages of aspen now reaching maturity.

The area has long been characterized as having an underutilized forest resource. And, while we do not wish to overlook the opportunities of using forest residues in flakeboard production, we intend to highlight the opportunities of the standing timber resource. In the first place, it is illogical to consider rough, rotten and salvable dead trees as a material source while overlooking unused sound material. Secondly, I think we often consider that large volumes of forest residues are generated as a by-product of sawlog production. But in our study area, log production--and this is mostly sawlogs as we have extremely limited veneer production--is not large, accounting for slightly over 15-1/2 million cubic feet of harvest in 1973. This is contrasted to a cut of approximately 72 million cubic feet of pulpwood.

In addition, much of this sawlog volume, especially the hardwood--and the cut is about evenly divided between softwood and hardwood--comes from what would be recognized as small sawlog trees. Thus, slash is mostly relatively small tops and limbs. Nor do we have large volumes of unused primary plant residues. Most of the larger sawmills have chippers and produce pulp chips from coarse mill residues. The larger mills in the area produce 10 to 25 million board feet annually.

What we do have is an available resource of standing timber, primarily aspen, that is underutilized and needs harvesting.

Availability of the Forest Resource

I will be using data from the 1962 forest survey of Minnesota. A new survey has recently been completed, but very limited information is as yet available. In 1962, we had 8-1/2 million acres of unreserved commercial forest land in our 6-county study area. This has been reduced to slightly less than 7-1/2 million acres in 1975, primarily because of the expansion of the no-cut zone of the BWCA and the land placed in the Voyageurs National Park and restricted from harvest.

Two-thirds of the area is in public ownership, one-quarter in private ownership, and six and one-half percent is owned by the forest industries, Table 1.

Table 1. - OWNERSHIP OF COMMERCIAL FOREST LAND, 1961-62

County	Total	Federal	State	County	Industry	Private
			(Thousand Acres)			
Aitkin	850.6	8.5	295.5	272.5	3.0	271.1
Carlton	367.0	8.5	51.6	103.5	10.9	192.5
Itasca	1,411.9	273.7	260.1	403.5	55.3	419.0
Koochiching	1,575.0	92.2	792.2	292.6	204.0	194.0
Lake	1,104.0	513.6	157.0	154.0	126.0	153.4
St. Louis	3,204.3	627.6	430.8	953.3	160.1	1,032.5
TOTAL	8,512.8	1,524.1 17.9%	1,987.2 23.3%	2,179.4 25.6%	559.3 6.6%	2,262.8 26.6%

Survey data showed approximately 69-3/4 million cords of growing stock timber in the study area, in 1962, Table 2. About 44-1/2 percent of this was softwood, 31-1/2 percent aspen, and 24 percent other hardwood; 74 percent was poletimber and 26 percent sawtimber. At that time, a calculation called managed harvest estimated that it would be desirable to harvest about one million cords each of softwood and aspen and a little less than 400,000 cords of other hardwoods.[1] Actual harvest was about 500,000 cords of softwoods, 320,000 cords of aspen, and 50,000 cords of other hardwoods, Table 3. In 1973, the softwood cut was about 450,000 cords, aspen had increased by about 60 percent to 615,000 cords and other hardwoods doubled to 112,000 cords. Current growing stock volume information is not available, nor is a current estimate of managed harvest.

Preliminary data for a portion of the area indicate current growing stock volumes may be nearly equal to the amount determined from the 1962 survey in spite of the loss of commercial forest acreage. The increased size of the vast amount of poletimber-sized material in the years since the 1962 survey could account for much of this. Thus, the resource could support 3 to 4 mills of the 150 MMSF size from aspen without consideration for the amount of other hardwoods or residue type fiber resources in the study area.

[1]Managed Harvest is an area control technique, and applies silvicultural guides showing rotation age, site index, and a management objective to survey plot data to estimate an amount that could be cut annually for the next 10 years, while improving tree stocking and bringing about a more even distribution of age classes.

Cost of Manufacturing Structural Flakeboard

Production costs for structural flakeboard in Virginia, Minnesota, are estimated to range from $136.40 to $220.33 per MSF - one-half inch, excluding wood costs. These costs vary by the size of the facility and the amount of preprocessing costs required when utilizing rough roundwood. For my comparison, I have selected the two larger production capacities and a furnish of 60 percent chips, 40 percent roundwood. I have noted that our expected furnish would be aspen roundwood, and the production costs for the chips--logs furnish includes some front-end cost for debarking and flaking. Production costs are: $148/MSF 1/2-inch in the 150 MM annual capacity mill and $153/MSF for the 112 MM capacity mill, exclusive of wood costs. Estimated cost for rough wood delivered to the mill is approximately $22 per cord or $20 per oven dry ton of wood (not including drying). This then yields a total production cost of $172 and $178/MSF calculated from the prediction equation developed for the Virginia, Minnesota, site for the two larger sized mills.

Likely Market Value for Structural Flakeboard

The structural sheathing market offers the best opportunity for structural flakeboard sales, and the material will have to compete with plywood sheathing in this market. Although Minneapolis-St. Paul is the closest major market, Chicago and other midwest markets would be needed to satisfy volume requirements for an efficient mill. I will use Chicago as a base in the following analysis, and because of shipping cost differentials, we have a $3/MSF advan-

Table 2. - VOLUME OF GROWING STOCK ON COMMERCIAL FOREST LAND BY SPECIES AND SIZE CLASS, 1961-62

County	Poletimber			Sawtimber		
	Softwood	Hardwood	Aspen	Softwood	Hardwood	Aspen
	(Thousand Cords*)					
Aitkin	853.0	1,756.7	1,311.2	349.2	1,150.6	121.1
Carlton	277.1	509.2	376.8	87.0	149.9	20.3
Itasca	3,058.8	2,564.8	4,445.0	1,960.0	1,029.8	693.7
Koochiching	6,207.7	1,535.7	3,261.4	1,878.3	745.9	642.0
Lake	3,052.1	1,857.4	1,787.0	1,761.1	436.3	702.8
St. Louis	7,150.1	3,894.4	7,691.5	4,475.6	941.3	1,010.8
TOTAL	20,598.8	12,118.2	18,872.9	10,511.2	4,453.8	3,190.7

*Unpeeled total net volume of all merchantable trees 5.0 inches, d.b.h.

	Total	Softwood	Other Hardwood	Aspen
Poletimber	51,589.9	20,598.8	12,118.2	18,872.9
Sawtimber	18,155.7	10,511.2	4,453.8	3,190.7
TOTAL	69,745.6	31,110.0	16,572.0	22,063.6

tage in Minneapolis-St. Paul. With spot market prices of $180, $200, or $220 f.o.b. mill for western 1/2-inch plywood per MSF we estimated delivered prices to Chicago distributors of $202, $220, and $238 when adjusted for standard industry discounts and transportation costs. Shipping costs from Virginia to Chicago are estimated to be $17/MSF for 1/2-inch structural flakeboard. The discounted f.o.b. mill value would then be competitive in Chicago at or below a price of $185, $203, or $221 per MSF. With production costs of $172 or $178 per MSF, production from both mill sizes appear competitive in Chicago, even when spot prices for Western plywood are in the $180 range, Fig. 2.

Conclusions

It appears that the aspen resource in northern Minnesota could support a 150 MMSF 1/2-inch basis structural flakeboard facility from the standing growing stock inventory. A clearer picture will be available very soon from the recently completed statewide forest survey. A small increase in delivered cost per cord might result from increased road building needs and harvesting lower density stands. This would be moderated to the extent that better utilization or use of residues might increase supply.

Plant sites in the study area on the Burlington Northern railroad allow one-line hauls to a large midwest area. A more competitive situation might result if increased shipping volume would allow reduced commodity rail rates. Currently, truck rates are lower to the Minneapolis market area.

Table 3. - GROWING STOCK VOLUME, ESTIMATED ANNUAL MANAGED HARVEST AND ACTUAL REMOVALS FROM GROWING STOCK, 1960-62

	Softwood	Other Hardwood	Aspen	Total
	(Thousand Cords)			
Volume of Growing Stock	31,110.0	16,572.0	22,063.6	69,745.6
Managed Harvest	1,031.6	383.0	1,028.7	2,443.3
Cut from Growing Stock	494.9	49.9	316.7	861.5

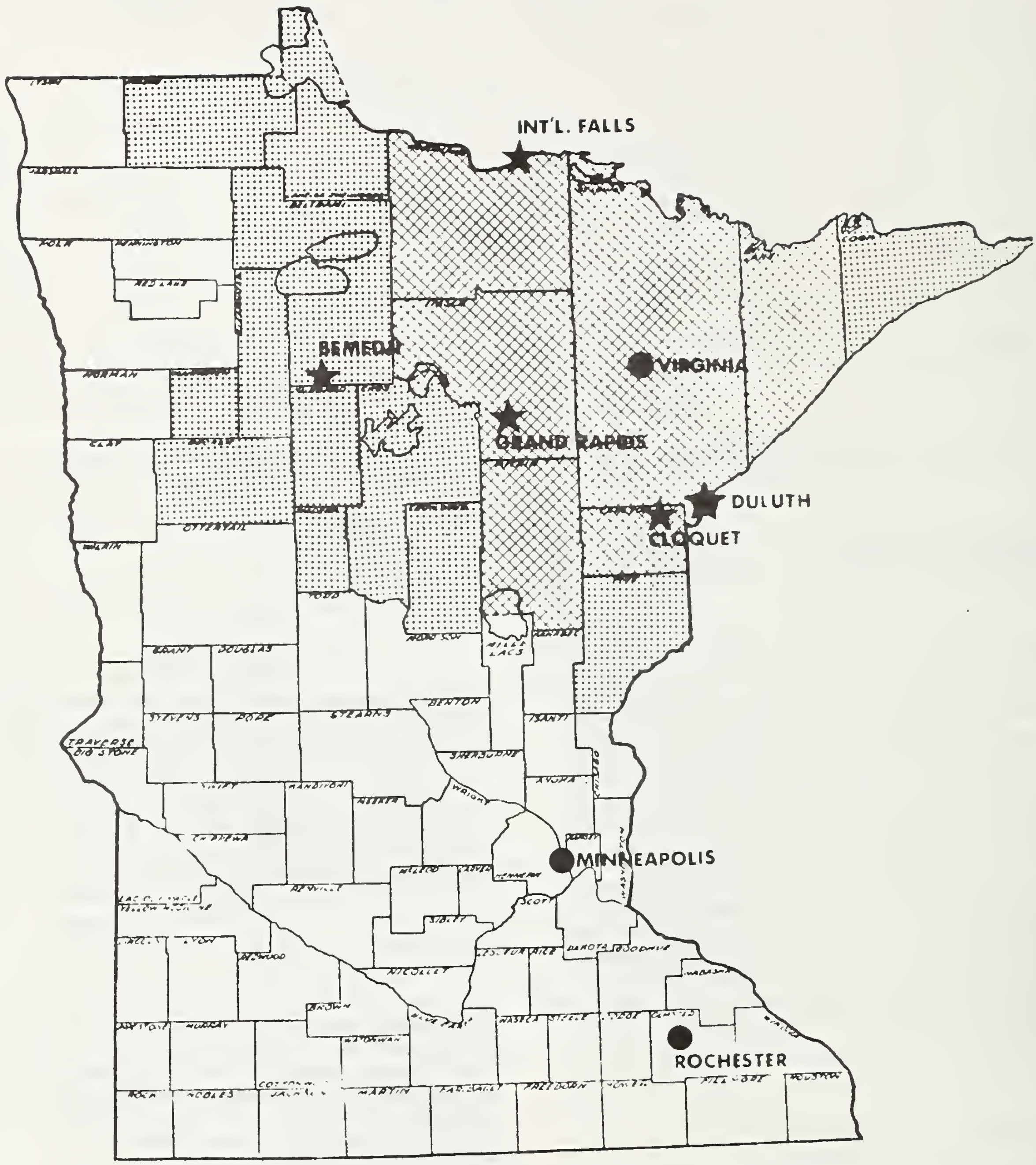
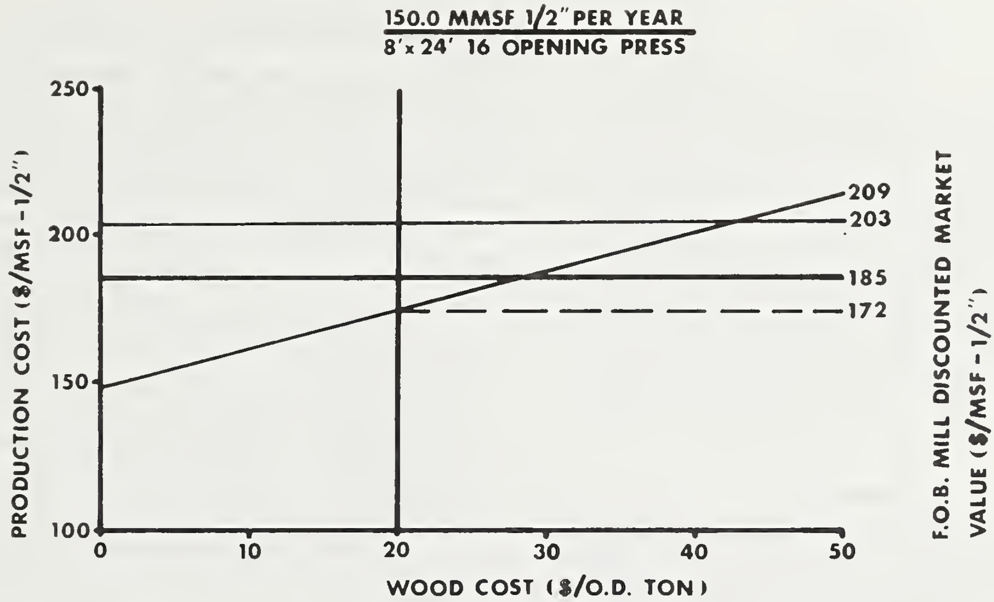


Figure 1. Map of Minnesota showing major population and wood use centers, 18 Northern forested counties and 6-County resource area.



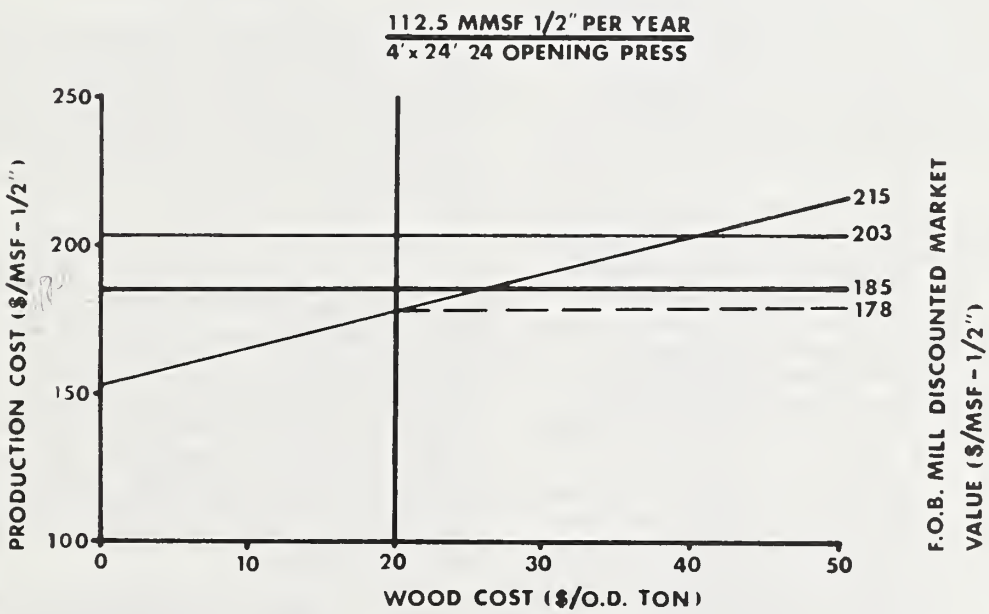


Figure 2. Production costs, including taxes and profit (15% IRR) and estimated F.O.B. mill market value for structural flakeboard in Virginia, Minnesota with 40% logs 60% chips furnish.

THE ECONOMIC FEASIBILITY OF MANUFACTURING STRUCTURAL FLAKEBOARD IN VERMONT

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Abstract

Opportunities for production of structural flakeboard in Vermont exist both in the supply of raw material and marketing of the final product. An analysis of economic impact of such factors as raw material supply, plant size, and product market price indicate feasibility at existing factor input costs and product prices. The analysis also revealed profitability to be highly sensitive to raw material cost and final product price. Price increases from increased competition for wood resource for energy generation or paper products could cause significant increases in final product price. Market acceptance is strongly predicated on a competitive price line with 1/2-inch CDX plywood.

Introduction

Forests are a flexible resource. Technology exists to convert forest resources from any given location to a multiplicity of products; recreation, water, wildlife, forage, direct energy (boiler fuel), indirect fuels (gas), primary products (poles, pilings, lumber, timbers, veneer), secondary products (pallets, furniture, pulp and paper, chemicals), and tertiary products (plastics, foods, fertilizers). The primary concern regarding use is economics, and more so a question of what use, rather than is it feasible. That is, the land manager must determine the maximum economic advantage of a particular wood resource given its alternative uses.

Past technology and supply and demand relationships have limited lower quality forest resource to lower value market products. Management philosophy has countered by emphasizing more intense management to develop veneer logs and high quality saw logs. In part, this has resulted in higher prices and consumption shifts to competitive materials. To counter, technology has been developed to turn low quality forest resource into higher quality products. Examples are: plywood, laminated beams, laminated ties, press board, and structural flakeboard.

Structural flakeboard can be produced from low quality hardwood and softwood resources which have limited marketability as either fuel wood or pulpwood (Fig. 1). New harvesting and processing technology, such as mechanized harvesters and shaping-lathe headrigs, provide the capability for increasing economic return from these otherwise non-marketable forest resource (1).

Structural Flakeboard Manufacture in Vermont

An evaluation of Vermont as a feasible location for a 150 mm square foot/year plant reveals that both present supply and market factors will support the venture. The analysis also identifies manufacturing costs to be sensitive to plant size and cost of raw material. The latter factor is critical in Vermont due to proposed plans for pelletized fuel production and power generation from wood.

Market evaluations revealed that projected new home and business construction and renovations afford potential for regional plant expansion. Further, structural flakeboard produced in Vermont, New Hampshire, or Maine may have location preference to regional buyers, as contrasted with present plywood suppliers in Canada, the South, and the West Coast. However, critical elements of the construction market are product allegiance and strong price competition. Market acceptance of 1/2-inch structural flakeboard over 1/2-inch CDX plywood will require education, and lower pricing to permit market penetration.

Figure 2 illustrates the economic factors necessary for effective structural flakeboard manufacture in Vermont. The success of such a venture relies heavily on a readily available supply of raw material and a regional market with demonstrated capability of supporting a suitable market price. A closer look at raw material supply, harvesting costs, product price, and their influence on profitability will illustrate these findings.

Raw Material Supply

It is estimated that approximately 40 billion cubic feet of growing stock exist in all six New England states. Of this, 22 billion cubic feet are softwood and 18 billion cubic feet are hardwood (Table 1). Further, the regional growth-harvest relationships that have existed over the last two decades appear to be in favor of increased supply (2).

Vermont has 4.7 billion cubic feet of growing stock increasing at a rate of 2.3 percent annually (2). The forests have reflected changing agriculture cycles over time. The vast forests of the 18th Century were all but erased by the mid-to-late 19th Century due to growth in both the wood products and agriculture industries. Vast acreages were cleared, leaving only 30 percent of the area forested by 1870 (3). The early 20th Century brought competition from Midwest agriculture and the number of farms declined. Rapid expansion of succession forest types has resulted in the present large forest acreage, amounting to 80 percent of the total land mass.

Table 1. -- NET VOLUME OF TIMBER ON COMMERCIAL FOREST LAND IN NEW ENGLAND.[1]

Species group	Source: Growing-stock trees	Source: Cull trees	Total
Softwoods	20.2	2.0	22.2
Hardwoods	15.0	3.2	18.2
Total	35.2	5.2	40.4

[1]Reference: James T. Bones. 1976. Potential sources of wood fiber in the Northeast. For. Products J. 26(2):30-32.

Today, Vermont's inventory of hardwoods comprise 60 percent of total growing stock. Species composition is predominantly hard maple, yellow birch, soft maple, and beech. Softwood species represented are primarily red and white pine, balsam fir, spruce, and hemlock (Table 2).

Commercial forest land totals 4.4 million acres or 75 percent of the state's land area (4). Ninety percent of the commercial forests are owned by over 77,000 different private owners, split between individuals (73,900), clubs and organizations (2,700), and corporations (700).

Quality

The quality of Vermont's forests reflect poor cutting practices and lack of effective management. Much of the forests are stocked with smaller pole size timber (Table 2). Further, quality appears to be decreasing over time in most species groups (4).

Quality is the strongest drawback when assessing Vermont's forests for traditional product markets. Much of the hardwood resource is of a quality that has limited potential for high quality lumber or veneer markets. This poses a critical question concerning future management. Needed intensive management to upgrade the quality of the resource cannot be properly implemented without treatment of lower quality material presently on the site. This can be accomplished either through public programing such as the forest improvement program (fip), or creating new markets such as structural flakeboard, pulp, or energy.

Owner Attitudes

Surveys of Vermont and New Hampshire timberland owners indicate that people who sell timber generally do so for businesslike reasons (5). That is, product maturity, finances, and business planning strongly relate to sales. People who do not sell do so for personal reasons, such as claiming that attractive vistas would be spoiled.

The Vermont survey also indicated that 88 percent of privately owned commercial forest land is owned by people who could harvest their timber (5). This totals to 3,517,300 acres or 3.8 billion cubic feet of inventory and 84.8 million cubic feet of annual net growth statewide. Further, the study revealed that approximately 11,000 owners (14 percent) would harvest some acreage within the next 10 years.

A 150 MM square foot structural flakeboard plant requires 159,750 OD tons annually, or 9.7 MM cubic feet of oven dry equivalent resource. The above estimates would indicate that plant needs could be supplied from current growth with sufficient resource for a present annual cut of 47 MM cubic feet. This is further supported by Table 3 which demonstrates that growth alone would exceed expected cuts plus input to 5 structural flakeboard plants.

In general, central Vermont affords the least supply constraints and minimum competition from pulp companies in New York, Canada, and New Hampshire. The reduced competition should minimize raw material and hauling costs and still provide direct access to coast markets in New York and Boston.

Harvesting Costs

The primary harvest method used in Vermont is the chainsaw-skidder system. During peak production periods over 300 logging contractors are operating statewide. The typical contractor operates one skidder and two cutters. Production ranges from 20 to 40 MBF (40 to 80 cords) per week with an average of 28 MBF (56 cords). In a pulpwood clearcut only half the above ground volumes are removed for sale.

A mechanized harvesting system generally harvests the above ground portion of the tree, which encompasses approximately 75 percent of total above ground volume. The number of these machines in Vermont presently varies between three and five. The system uses a mechanical shearer, forwarder, and chipper. Capital outlay for a complete system can

Table 2. -- VOLUME OF GROWING STOCK ON VERMONT'S COMMERCIAL FOREST LAND.

Unit and county	Forest-land area: Commercial	Forest-land area: Percent of total land area	Sawtimber growing stock	Pole timber growing stock	Total growing stock	Growing stock per acre
	-----Thousand acres-----		-------Millions of cubic feet--------			Cubic feet
Caledonia	291.3	74	150.6	151.7	302.3	1,037.7
Essex	396.1	93	241.1	238.9	480.0	1,211.8
Franklin	236.9	56	89.0	101.8	190.8	805.4
Grand Isle	--	--	--	--	--	--
Lamoille	251.2	83	146.1	146.5	292.6	1,164.8
Orange	335.9	76	172.8	179.6	352.4	1,049.2
Orleans	339.0	74	181.6	183.5	365.1	1,076.9
Washington	361.3	80	202.0	202.8	404.8	1,120.4
Northern Unit	2,211.7	75	1,183.2	1,204.8	2,388.0	1,079.7
Addison	285.8	57	143.6	132.9	276.5	967.4
Bennington	370.7	86	206.3	193.6	399.9	1,078.7
Chittenden	195.7	57	94.5	94.5	189.0	965.7
Rutland	444.9	75	237.1	225.7	462.8	1,040.2
Windham	428.5	85	242.2	231.1	473.]	1,104.5
Windsor	492.6	80	279.1	261.6	540.7	1,097.6
Southern Unit	2,218.2	74	1,202.8	1,139.4	2,342.2	1,055.9
Total	4,429.9	75	2,386.0	2,344.2	4,730.2	1,067.8

vary between $250 M and $500 M. Such a system can harvest 5 acres a day. Yields with mechanized harvesters in Vermont average 35 to 45 cords per acre with cruise estimates ranging between 20 and 25 cords per acre (3).

Environmental attitudes and capital availability will slow transfers to mechanized total tree harvest systems in Vermont. Therefore, expected wood harvest costs for input to a flakeboard plant must represent both conventional and mechanized system costs. Tonnage yield per acre and harvest costs predicated on a 40 percent round wood and 60 chips harvest system appear realistic for a plant being established today.

Table 3.--PROJECTIONS OF NET ANNUAL GROWTH, TIMBER REMOVAL, AND INVENTORY OF GROWING STOCK AND SAWTIMBER ON COMMERCIAL FOREST LAND IN VERMONT, 1973 to 2003.[1 2]

	1973 (Inventory year)	1983	1993	2003
		Growing stock		
	--Million cubic feet--			
Removals	47.8	68	97	127
Growth	106.6	122	139	154
Inventory	4,730.2	5,189	5,673	6,020

[1]Kingsley, Neal P. 1977. The forest resources of Vermont. U. S. Dep. Agric. For. Serv. Resour. Bull. NE-46.

[2]Assumptions: commercial forest land will begin slow decrease after 1980; net annual growth as a percent of inventory is expected to increase from 2.3 to 2.6 percent; timber removals will reflect expected timber-product demands and land-use changes.

Costs of raw material for a structural flakeboard plant will closely approximate current stumpage, harvest, and transfer costs for pulpwood. Pulpwood is the second major product harvested in Vermont, with over 140,000 cords marketed annually (Table 4).

As previously noted, a central Vermont plant location would minimize competition with pulp companies in New Hampshire, Vermont, and Canada. U. S. Forest Service projections indicate a gradual rise in demand for pulpwood in Vermont, but mostly in present high demand areas (4).

Although studies have not been completed to fully access the comparative economics of conventional and mechanized harvest costs in Vermont, reliable estimates by professional foresters and industry personnel are available.

The total cost of a cord of wood f.o.b. the mill site are estimated in Table 5 at $21.30 from a conventional system and $19.45 from a mechanized system. The labor costs of limbing and bucking are not necessary with the mechanized system and are shown to be zero. However, with hardwood, to gain maximum recovery and productivity per hour, a cost may be necessary to collapse the extreme branching in maple and birch. Estimated costs of screened chips f.o.b. plant site on an ODT basis are $21.33 and $18.82, respectively.

Product Markets and Pricing

The Northeast has one of the largest building and renovation markets in the United States. Structural flakeboard would find extensive use in general construction for sheathing and underlayment and as decorative paneling, either exterior or interior. The sheathing market is now held primarily by CDX grade 1/2-inch plywood.

Plywood marketed in New England is shipped primarily from southern pine and western fir mills. New England based flakeboard plants would have to price below the current $250 to $270/M sq.ft.[1] price of 1/2-inch plywood to be competitive. In the current market, plywood prices reflect transfer costs of $20 to $30 from southern pine plants and $35 to $45 from western fir plants.

Market penetration pricing 10 to 15 percent below 1/2-inch agency grade CDX 4-5 ply plywood should gain product acceptance by building contractors. Pricing in the $220 to $230/M sq.ft. range f.o.b. New York and Boston markets would permit broker's fees and transfer costs of $10 to $20/M sq.ft. and a manufacturing cost of $200 to $210.

Production Costs and Profitability

The costs of manufacturing sheathing material is strongly related to variable input costs for wood, resin, and fuel. As related in Figure 2, these account for over 60 percent of total costs. Wood feedstock, at 15 percent of total costs, was found to severely impact plant profitability at prices above $27/ODT. Figure 4 relates the effect of rising wood costs on total costs and firm profits. A $14 rise per ODT all but erases profit taking at a market price of $200/M sq.ft. This demonstrates the critical aspect of necessary cost control in harvesting and transfer of round wood and chip inputs.

Anticipated marketability of structural flakeboard in New York and Boston markets would be competitive at 85 percent of the market price ($260) for agency grade CDX 1/2-inch plywood. A price below $200/M sq.ft. would not yield sufficient profit taking, whereas a price approaching $260 would probably limit builder and consumer acceptance.

Market price received impacts NPW of the plant investment. At prices below $200/M sq.ft. the investment of $22.4 MM would not yield a 15 percent ROI (after tax) (Fig. 4). However, at $220/M sq.ft. and above, the investment yielded high net present worth. Further, these present values remained positive at wood costs exceeding $30/ODT.

Investment payback period is significantly reduced at higher market price (Fig. 5). In general, payback period is reduced by 40 percent or more when moving from a market price of $180/M sq.ft. to $260/M sq.ft. Wood cost had little effect on payback, regardless of price level. In general, less than a year difference occurred over the range of wood costs.

[1]Point pricing estimates. Based on prices from wholesale shippers in Vermont, New York, and Connecticut (Feb. to Mar., 1978).

Table 4. -- TIMBER REMOVALS FROM GROWING STOCK AND SAWTIMBER ON COMMERCIAL FOREST LAND, BY ITEMS, SOFTWOODS AND HARDWOODS, VERMONT, 1972.[1]

Item	Growing stock			Sawtimber		
	All species	Soft-woods	Hard-woods	All species	Soft-woods	Hard woods
	--------Thousand cubic feet--------			-------Thousand board feet[2]---------		
Roundwood products:						
Sawlogs	17,811	7,425	10,386	87,882	35,689	52,193
Veneer logs and bolts	1,055	--	1,055	4,711	--	4,711
Pulpwood	9,604	4,535	5,069	34,372	15,374	18,998
Piling	54	48	6	265	234	31
Poles	5	5	--	12	12	--
Posts	382	316	66	1,023	858	165
Other	2,575	689	1,886	6,538	1,869	4,669
Fuel wood	1,388	--	1,388	1,243	--	1,242
All products	32,874	13,018	19,856	136,046	54,036	82,010
Logging residues	8,189	2,689	5,500	15,608	4,498	11,110
Other removals	6,895	2,943	3,952	13,142	4,866	8,276
Total removals	47,958	18,650	29,308	164,796	63,400	101,396

[1]Kingsley, Neal P. 1977. The forest resources of Vermont. U. S. Dep. Agric. For. Serv. Resour. Bull. NE-46.

[2]International 1/4-inch rule.

Table 5. -- COMPARATIVE COST ESTIMATES OF CONVENTIONAL AND MECHANIZED SYSTEMS.

Cost elements	Systems	
	Conventional[1]	Mechanized[2]
Stumpage	$ 3.30	$ 2.50
Felling	1.10	1.65
Limbing and topping	2.20	-0-
Bucking	3.30	-0-
Skidding	4.40	4.95
Chipping	-0-	3.95
Transport	7.00	6.40
Delivered cost	21.30	19.45
Bark and wood loss[3]	3.83	3.50
Debarking, chipping, screening	4.73	3.40
Total cost screened chips--cord basis	29.86	26.35
Oven dry ton basis	21.33	18.82

[1]Chainsaw felling, rubber tire or track vehicle skidding.

[2]Mechanized shearing, rubber tire forwarders, mobile chipper.

[3]Estimated at 18 percent of delivered cost (3).

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2. Bones, James T. 1976. Potential sources of wood fiber in the Northeast. For. Prod. J. 26(2): 30-32.

3. Rich, J. P. 1975. The feasibility of generating electricity in the State of Vermont using wood as a fuel--a study. J.P.R. Associates, Inc., Stow, VT.

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Figure 1.--Extensive forest areas in Vermont and New England are overstocked with small undesirable species of limited marketability.

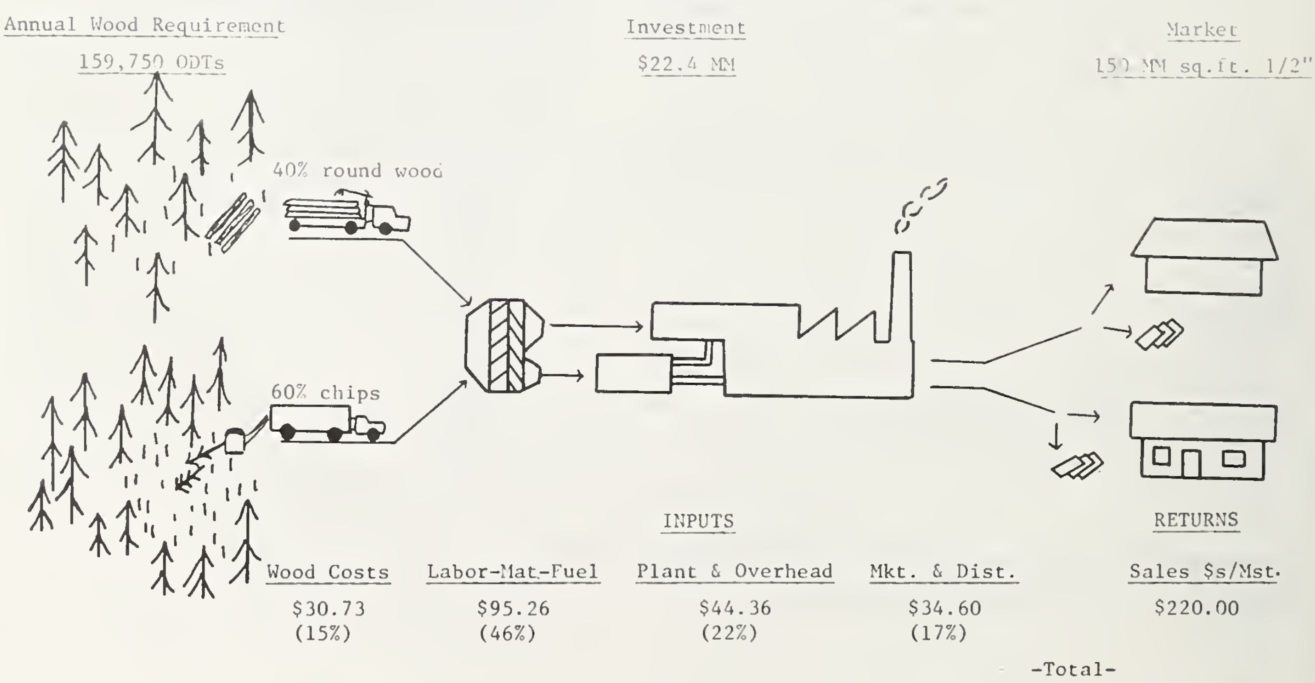

Figure 2.--Economic inputs and returns from the structural flakeboard manufacturing process.

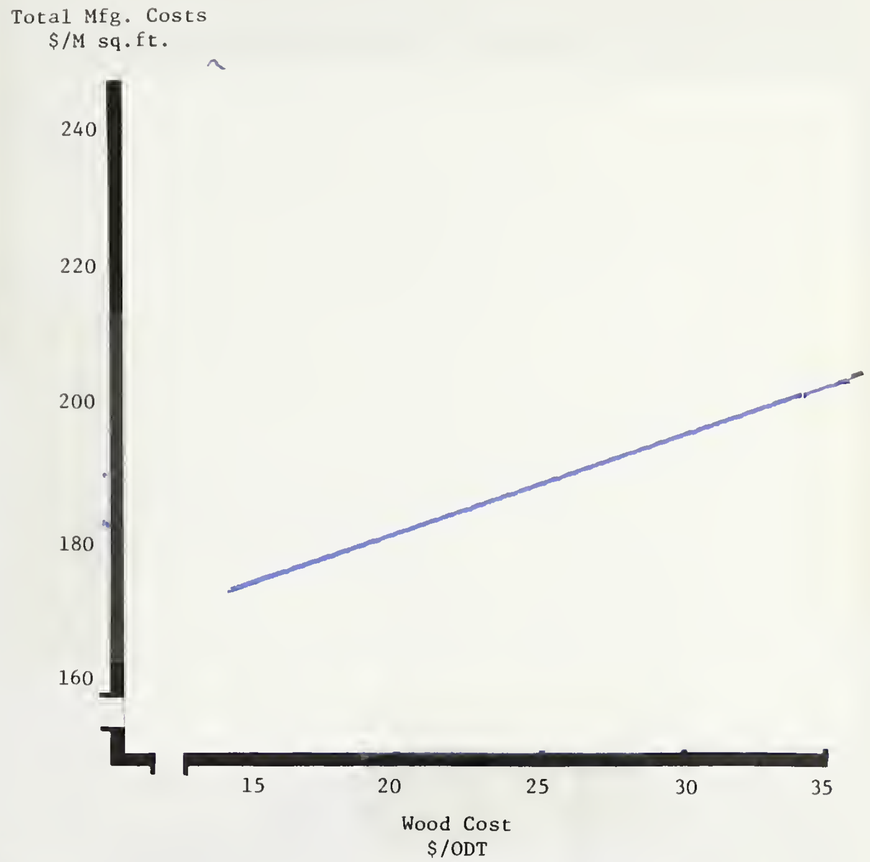

Figure 3.--Effects of raw material cost on total manufacture costs of

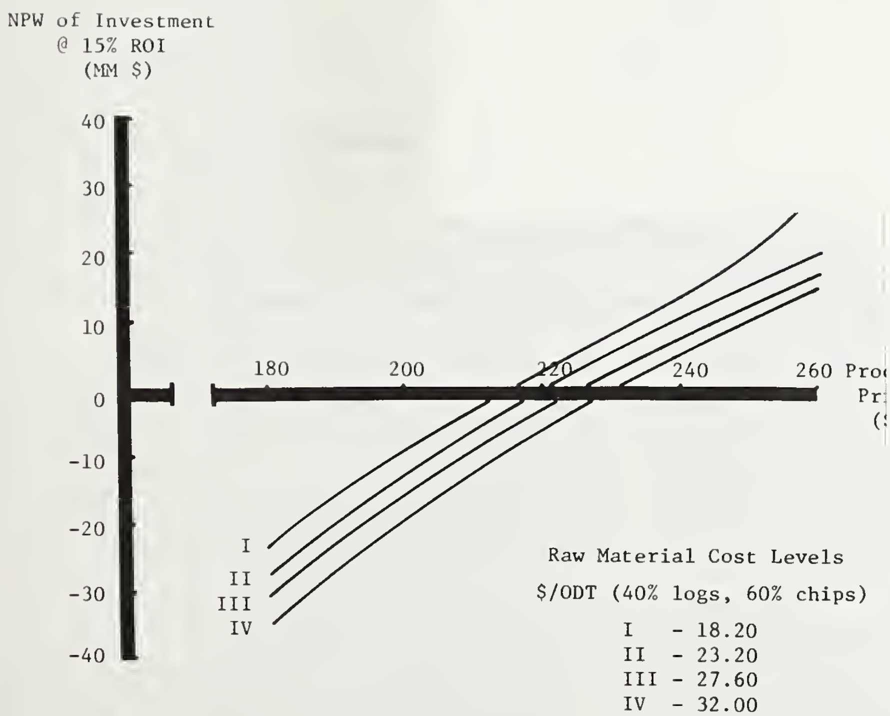

Figure 4.--Effect of raw material cost and product price on profitability of 150 MM square foot flakeboard plant.

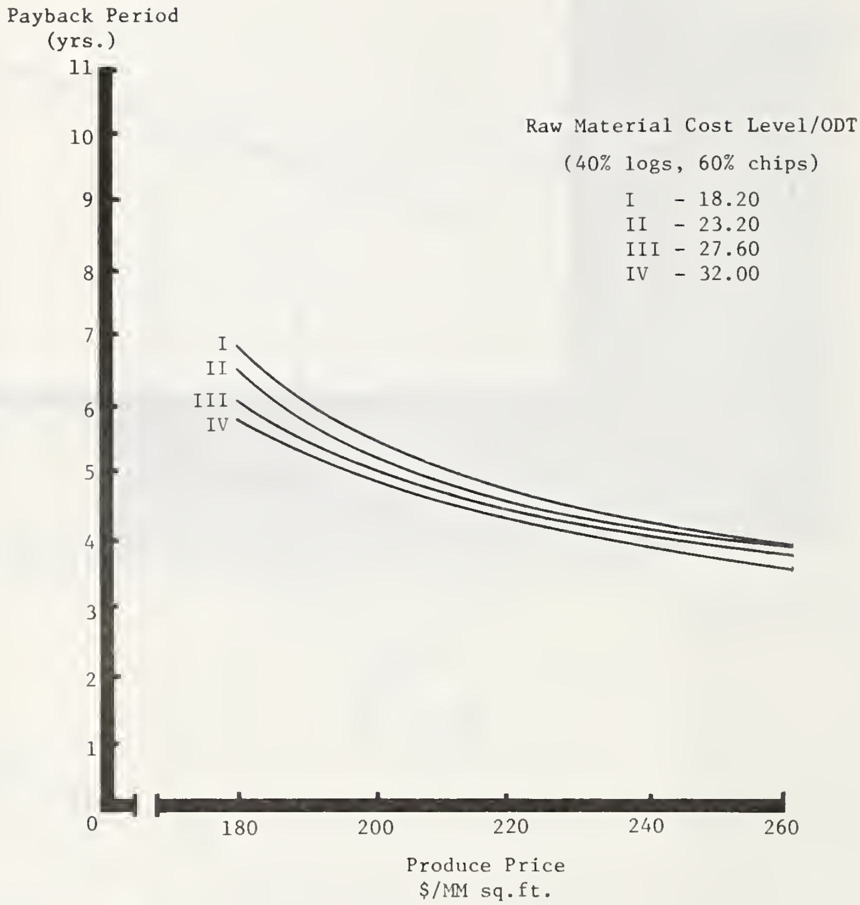

Figure 5.--Effect of raw material cost and product price on payback period.

FEASIBILITY OF STRUCTURAL FLAKEBOARD MANUFACTURE: LARAMIE, WYOMING

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Abstract

An environmentally desirable mode of operation for a plant at Laramie would be to utilize wood raw materials in the following order of priority: 1) forest residues removed with live sawtimber, 2) small roundwood thinnings removed with sawtimber in multiproduct sales or in designated small roundwood sales, and 3) sawmill residues. However, business economics favor this priority: 1) sawmill residues, 2) small roundwood from multiproduct sales, 3) forest residues from multiproduct sales, and 4) small roundwood from designated small roundwood sales. A Laramie plant should be economically feasible under certain circumstances. A plant with a production capacity of 112.5 million square feet of flakeboard per year (1/2" basis) should be more efficient than plants built to produce at levels of 37.5, 75.0, or 150.0 million square feet per year.

Introduction

Public and private groups are increasingly interested in the feasibility of producing both particleboard and structural flakeboard in the central Rocky Mountain region. Unused wood raw materials in the area include standing and down salvable dead trees, other small and unmerchantable roundwood, logging residues, and processing plant residues. Flakeboard production, probably the most compatible with existing forest industries in the central Rocky Mountains of any new forest-based industry, could provide outlets for roundwood that should be harvested to improve management of the area's forests. Use of unutilized wood resources would also enhance the area's general economic conditions.

The problem studied was whether a Laramie producer could derive sufficient advantage from his geographic location, available raw materials, production techniques, or production costs to compete in the flakeboard industry under existing or foreseeable conditions. Estimates of production costs, likely selling prices, and investment feasibility were developed for four hypothetical plants at Laramie.

Laramie was subjectively judged to be one of the most favorable sites in the area because there is a greater availability of forest and mill residues compared with other sites in the area. The City is also located on major transportation routes. Both the mainline of the Union Pacific Railroad and Interstate Highway 80 pass through Laramie, which would facilitate transportation of both raw materials to the manufacturing plant and the finished product to the market. The necessary professional and skilled workers could be attracted to Laramie because of well developed commercial, educational, cultural, and medical facilities and superior outdoor recreational opportunities for hunting, fishing, skiing, and hiking. Many people would consider Laramie a desirable place to live.

Availability of Wood Raw Materials

The types of wood raw material available are critical for flakeboard manufacture. Coarse sawmill residues, forest residues and small roundwood from either multiproduct sales or designated small roundwood sales are important because of different costs associated with each, and the available volume. The coarse sawmill residues are slabs, edgings, and trim from the live sawlogs. The forest residues are salvable standing and down dead material including mortality and logging residues. The small roundwood from multiproduct sales is that harvested in combination with sawlogs. Such roundwood on National Forest lands would come mostly from the Standard and Special components.[1] Small roundwood from designated small roundwood sales would come primarily from the Marginal component of National Forests.[1] The small roundwood on other ownerships would be found on land types similar to that of the National Forests. Considering these sources, the

[1]Standard component -- The component of the regulated forest land suitable and available for timber production on which crops of industrial wood can be grown and harvested with adequate protection of the forest resources under the usual provisions of the timber sale contract.
Special component -- That part of the regulated forest land suitable and available for timber production which is recognized in the Multiple Use Plan as needing specially designed silvicultural treatment of the timber resource to achieve landscape or other key resource objectives.
Marginal component -- A component of forest land suitable for regulated timber production but not currently available because of constraints from associated resource needs, high development costs and low product values, or absence of market for the species or product available.

estimated volumes of residues and roundwood tributary to Laramie that are potentially usable for flakeboard are as follows:

Material	[2]Thousand cubic feet	[2]Thousand oven dry tons
Existing forest residues[3]		
Standing dead	37,620	446
Down dead	217,282	2,575
Total dead	254,902	3,021
Logging residues per year[3]	1,670	20
Additional mortality per year[3]	10,427	124
Coarse sawmill residue per year[3]	4,219	50
Small roundwood per year[4,5,6]	12,940	153

The volume of coarse sawmill residues is based on the production of sawmills in the area. The volume of small roundwood was determined from potential yields of the Medicine Bow, Routt, and Roosevelt National Forests. Data on potential yields of materials from state, county, and private lands were not available, but volumes from these sources would be significant and could provide an additional supply "cushion".

An environmentally desirable mode of operation for a particleboard plant at Laramie would be to utilize wood raw materials in the following order of priority: 1) forest residues removed with live sawtimber, 2) small roundwood thinnings removed either with sawtimber in multiproduct sales or alone in designated small roundwood sales, and 3) coarse sawmill residues. However, as shown later in this report, economics favor this priority: 1) coarse sawmill residues, 2) small roundwood in multiproduct sales, 3) forest residues from multiproduct sales, and 4) small roundwood from designated small roundwood sales.

Flakeboard performance may vary depending upon the size, shape, and surface quality of the flakes. Flakes produced from drier dead material in some cases may not be as uniform as those from living material. Consequently, the performance of flakeboard made with live and dead materials may vary depending upon the mix.

The supply of materials available to a Laramie flakeboard plant was projected on the basis of sawmill production in the tributary area. Live sawtimber, live small roundwood, and forest residues could be harvested together in multiproduct sales and skidded, loaded, and hauled in tree lengths to the sawmill and bucked there for maximum product recovery. Small roundwood, forest residues not suitable for sawlogs, and tops from sawtimber would be chipped into 2- to 3-inch length chips. These chips, together with those from the coarse sawmill residues, would be shipped to the flakeboard plant in chip vans.

The estimated annual volumes of wood raw materials available for flakeboard based on average sawmill production from multiproduct sales would be as follows:

Material	Thousand cubic feet	Oven dry tons
Forest residues (all types)	3,485	41,290
Small roundwood	2,954	35,040
Coarse sawmill residues	4,253	50,440

An additional 90 thousand oven dry tons of material from designated small roundwood sales from the Marginal component of the National Forests would also be available annually.[4,5,6]

The gross volume of forest residues, all types, was assumed to be 800 cubic feet per acre. It was further assumed that half of this volume would be sawed into lumber and the other half chipped at the sawmill. Only 75% of the gross log volume was assumed to be suitable for lumber and flakeboard chips combined. Similarly, only 75% of the coarse residues

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[2]Calculated on the basis of 1 ft^3 = 23.7 oven dry pounds.

[3]Anderson, T. et al. 1975. Availability of wood raw materials at selected Rocky Mountain locations. Unpublished report of a cooperative study made by Colorado State University and the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

[4]USDA Forest Service. 1975. Timber Management Plan. Medicine Bow National Forest, Laramie, Wyo.

[5]USDA Forest Service. 1975. Timber Management Plan. Routt National Forest, Steamboat Springs, Colo.

[6]USDA Forest Service. 1975. Timber Management Plan. Roosevelt National Forest Extension, Fort Collins, Colo.

volume from sawed material was assumed to be suitable for chips. The cubic volume recovery of chips suitable for flakeboard production from roundwood was assumed to be 100 percent. The volume of small roundwood removed with sawlogs from multiproduct sales was considered to be in the same proportion as the volume of small roundwood to sawtimber shown in potential yield statements for the Standard and Special components of the Medicine Bow, Routt, and Roosevelt National Forests.[4,5,6]

Delivered Wood Costs

The delivered wood costs include all costs incurred in delivering woodchips to the plant site at Laramie. Costs were developed separately for forest residues, small roundwood in multiproduct sales and designated small roundwood sales, and for coarse sawmill residues (Table 1). Most of the costs were derived from Forest Service timber appraisal guides for the area. The cost of hauling chips from sawmills to the flakeboard plant were derived from a hauling cost equation developed by Withycombe (1). These derived costs were then adjusted for inflation.

Forest Residues

Forest residues were assumed to carry the same costs for felling and bucking, skidding, loading, overhead, and hauling as live sawtimber. Road costs, including maintenance, slash disposal, erosion control, and temporary development were assigned only to live sawtimber. On this basis, the total cost of forest residues delivered to the sawmill was $56.06 per thousand board feet (MBF). The cost of chips delivered to the flakeboard plant was $44.11 per oven dry ton, assuming that 1.5 oven dry tons of chips are produced from each MBF of timber directly chipped and that .35 oven dry ton of chips is produced from coarse sawmill residues for each MBF sawed into lumber. The debarking and chipping cost was estimated to be $14.00 per MBF, and the f.o.b. mill market value of chips produced from coarse sawmill residues was the same as for chips from live sawtimber--$7.50 per oven dry ton. Moisture content of chips made from partially dry residues was assumed to be 30 percent, based on oven dry weight.

Small Roundwood in Multiproduct

Felling, bucking, skidding, overhead, and hauling costs were assigned to small roundwood in multiproduct sales. Road--including maintenance--slash disposal, erosion control, and temporary development costs were charged to the live sawtimber. The moisture content of chips produced from green roundwood, when shipped from the sawmills to the flakeboard plant, was assumed to average 70% based on oven dry weight. A total cost of chips of $42.18 per oven dry ton, delivered to the flakeboard plant, includes a cost of $28.81 for roundwood delivered to the sawmill, $7.00 for debarking and chipping at the sawmill, and $6.37 for hauling chips to the flakeboard plant.

Small Roundwood in Designated Small Roundwood Sales

Small roundwood in designated small roundwood sales would have to carry road maintenance, slash disposal, erosion control, and temporary development costs in addition to other logging costs shown for small roundwood in multiproduct sales. These additional costs were based on timber appraisal information for five sales on the Medicine Bow, Routt, and Roosevelt National Forests during 1975. A total cost of $47.51 per oven dry ton of chips delivered to the flakeboard plant includes an average cost of $34.14 for roundwood delivered to the sawmill, $7.00 for debarking and chipping at the sawmill, and $6.37 for hauling chips to the flakeboard plant. The above total costs do not include the cost of building primary roads into some presently unroaded areas. Building such roads would probably add another $5.00 to $7.00 per oven dry ton if their cost was entirely assigned to the timber cut.

Coarse Sawmill Residues from Live Sawlogs

The f.o.b. mill market value of pulpchips produced from live sawlogs at sawmills was estimated to be $7.50 per oven dry ton, based on an average pulpchip value of $9.00 per unit (2,400 o.d. lbs.) during 1975.[3] An estimated total cost of $13.00 per oven dry ton delivered to the flakeboard plant includes $5.50 for hauling. The moistrue content of these chips was assumed to be 30%.

Cost of Manufacturing Flakeboard

Estimated costs of producing structural flakeboard at Laramie, Wyoming, range from approximately $125 to $202 per thousand square feet 1/2-inch basis (MSF - 1/2"), excluding wood costs (see page 150). These production costs depend largely on the size of the facility and to some extent on the cost of preprocessing roundwood and chips at the facility. The full cost, including wood costs, of producing structured flakeboard in different types and sizes of facilities are estimated in Figure 1. The product envisioned was a three-layer flakeboard with the faces of larger flakes and the cores of smaller flakes and other material produced from the chips.

Only a 40% flake/60% chip facility with press capacities of 37.5, 75.0, 112.5, and 150 million square feet - 1/2-inch basis (MMSF - 1/2") was considered for Laramie, since furnish in chip form

Table 1. — ESTIMATED COST OF DIFFERENT WOOD MATERIALS TO PARTICLEBOARD PLANT

Type of activity and cost	Forest residues	Small roundwood, multiproduct sales	Small roundwood, small roundwood sales	Coarse sawmill residues-live sawlogs
	($/MBF[a])	($/cord[b])	($/cord[b])	($/o.d. ton)
Logging				
Fell and buck	11.00	5.98	5.98	--
Skid	16.34	8.90	8.90	--
Load	5.48	2.98	2.98	--
Overhead	7.47	3.74	3.74	--
Haul	14.77	6.71	6.71	--
Road maintenance	--	--	.92	--
Slash disposal	--	--	3.18	--
Erosion control	--	--	.04	--
Temporary development	--	--	1.19	--
Stumpage	1.00	.50	.50	--
Cost to sawmill	56.06	28.81	34.14	7.50
Debarking and chipping	14.00	7.00	7.00	--
Chips from sawed dead material	2.63	--	--	--
Chip haul	8.92	6.37	6.37	5.50
Delivered wood cost	81.61	42.18	47.51	13.00
Cost per oven dry ton[c]	44.11	42.18	47.51	13.00

[a]Each MBF of forest residues directly chipped yields about 1.50 oven dry tons of chips; an additional .35 oven dry ton of chips is realized from the coarse residues of each MBF sawn into lumber. Thus, about 1.85 oven dry tons of chips are recovered per MBF of forest residues chipped.

[b]Each cord chipped yields about 1.00 oven dry tons of chips.

[c]Allowances for profit and risk were not included in delivered wood costs.

would be the only wood material that could be feasibly supplied to the plant. It was assumed that facilities of each of the different sizes could manufacture board from 100% chips at the same cost as from a 40% flake/60% chip mixture.

Total costs of producing structural flakeboard, including a composite capital cost of 15%, was estimated for each size of facility, utilizing wood raw materials in the following priority: 1) coarse sawmill residues, 2) forest residues, 3) small roundwood in multiproduct sales, and 4) small roundwood in designated small roundwood sales. This priority was based on both economic and environmental considerations. The total production and wood raw material costs and wood raw material volumes required for each size facility were:

1. Facility with 37.5 MMSF (1/2") capacity (per year) and 4' x 8' 24-opening press.

A total production cost of $193.17 per MSF would be incurred using coarse sawmill residues at $13.00 per oven dry ton. Available coarse residues of 50,440 oven dry tons would be ample to supply the 38,650 oven dry tons required annually by the plant. The mixing of any other type of material with coarse sawmill residues would obviously increase the total production costs per MSF.

2. Facility with 75.0 MMSF (1/2") capacity (per year) and 4' x 16' 24-opening press.

A total production cost of $166.07 per MSF would be incurred using 76,500 oven dry tons at $23.60 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume O.d. tons	Cost per oven dry ton Dollars
Coarse sawmill residues	50,440	13.00
Forest residues	26,060	44.11

The entire available supply of coarse sawmill residues would be utilized, plus about half as much forest residues.

3. Facility with 112.5 MMSF (1/2") capacity (per year) and 4' x 24' 24-opening press.

A total production cost of $161.23 per MSF would result from using 114,450 oven dry tons at $30.02 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume O.d. tons	Cost per oven dry ton Dollars
Coarse sawmill residues	50,440	13.00
Forest residues	41,290	44.11
Small roundwood from multi-product sales	22,720	42.18

The entire available supply of both coarse sawmill and forest residues would be utilized, with about a fifth of the requirement being supplied by small roundwood.

4. Facility with 150.0 MMSF (1/2") capacity (per year) and 8' x 24' 16-opening press.

A total production cost of $163.47 per MSF would result from using 149,600 oven dry tons at $33.69 per oven dry ton. The chip mix would consist of the following:

Wood raw material	Annual volume O.d. tons	Cost per oven dry ton Dollars
Coarse sawmill residues	50,440	13.00
Forest residues	41,290	44.11
Small roundwood from multi-product sales	35,040	42.18
Small roundwood from designated small roundwood sales	22,830	47.51

The entire available supply of coarse sawmill residues, forest residues, and small roundwood in multiproduct sales would be utilized, plus almost a sixth of the requirement coming from small roundwood sales.

Likely Market Value of Structural Flakeboard

Development of high volume markets for structural flakeboard will require expanded use of this type product in floor, roof, and wall sheathing; combination sheathing-siding; and siding. To compete with plywood, flakeboard will have to be sold at or below the price of comparable plywood. The most comparable plywood sheathing product on the market today is C-D exterior grade, 1/2" thickness.

Two major market areas were originally considered for study as potential outlets for Laramie-produced flakeboard--Omaha and Denver. Omaha was selected as the prime market area after considering both the average price paid by distributors for C-D exterior grade, 1/2-inch plywood, and the freight cost for shipping 1/2-inch structural flakeboard from Laramie. Denver was not selected because of the low average price of the plywood. The average delivered price for C-D exterior plywood, f.o.b. Omaha, was about $198 per MSF (1/2") in 1976. The estimated price of structural flakeboard from Laramie would range from $178 to $198 per MSF (1/2") f.o.b. Omaha. Since the 1976 freight cost would have been about $24 per MSF (1/2") from Laramie to Omaha, a residual f.o.b. plant value would have then ranged from about $154 to $174.

Conclusions

The financial analysis indicated that under the assumptions used a Laramie facility built to produce 112.5 MMSF (1/2" basis) of flakeboard per year would be more economically efficient than a plant to produce at levels of 37.5, 75.0, or 150.0 MMSF (1/2"). Total production costs and the costs of wood materials for each facility size are estimated as follows:

Plant size MMSF - 1/2"	Total production cost $/MSF-1/2"	Cost of wood raw materials $/o.d. ton
37.5	193.17	13.00
75.0	166.07	23.60
112.5	161.23	30.02
150.0	163.47	33.69

The smallest plant size is least efficient, even though its cost of wood raw materials is lowest. The economies of scale begin to be offset by the higher cost of wood raw materials, however, as forest residues and roundwood become a greater proportion of the necessary raw material mix for plants of larger size.

Other possible cost factors are illustrated by the example that the total production costs for the 150.0 MMSF (1/2") facility would rise from $163.47 to $164.34 per MSF (1/2") if wood costs increased $5.00 per cord or oven dry ton to cover primary road construction for designated small roundwood sales.

Total production costs for the 75.0, 112.5, and 150.0 MMSF (1/2") plants appear to be marginally within the range of 1976 f.o.b. plant values ($154 to $174) estimated for flakeboard sold in Omaha. The total production cost of $193.17 for the 37.5 MMSF (1/2") plant, however, greatly exceeds the maximum estimated plant market value.

Reference

1. Withycombe, R. 1975. The outlook for particleboard manufacture in the Northern Rocky Mountain region. USDA For. Serv. Gen. Tech. Rep. INT-21, 39 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

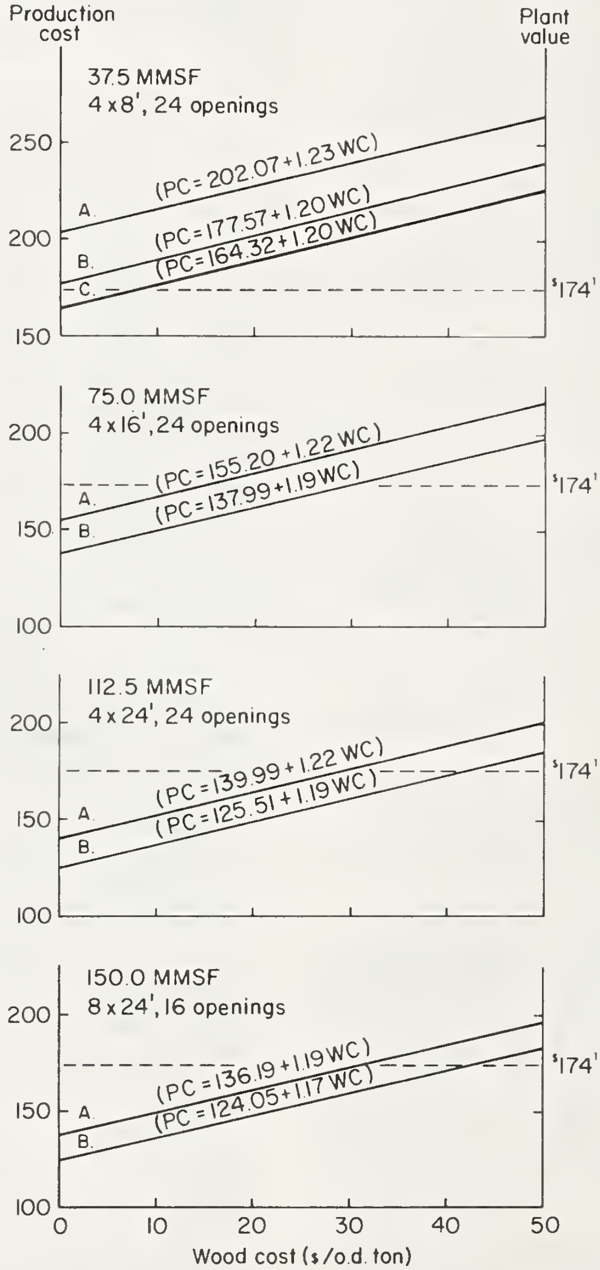

Figure 1.--Production costs ($/MSF) including taxes and cost of capitol (15% IRR) and 1976 estimated f.o.b. plant value ($/MSF) for 1/2" structural flakeboard manufactured from four facilities with varying annual capacities sited in Laramie, Wyo. (A. = 40% logs, 60% chips; B. = 40% flakes, 60% chips; C. = 100% flakes)

[1]Maximum estimated plant value of flakeboard.

PROSPECTS FOR STRUCTURAL FLAKEBOARD MANUFACTURING IN THE NORTHERN ROCKIES

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Abstract

The northern Rocky Mountain region is heavily forested with mixed conifers, and contains large volumes of forest residues. Two areas have been selected as typical of the region: Western Montana and Southeastern Idaho. The residues in western Montana are dead or cull material that will be available as an adjunct to logging for sawlogs, while the material in southeastern Idaho consists primarily of lodgepole pine recently killed by bark beetle infestation.

The costs of harvesting the forest residues are estimated at $22.38 per oven-dry-ton in western Montana, and $29.91 per ODT in southeast Idaho. The costs of converting the material to structural flakeboard is not significantly different from the costs found for other potential manufacturing sites in the United States, but the high transportation costs to the primary marketing areas make the manufacture of structural flakeboard economically infeasible at present prices. A sustained price increase of about 10 percent above 1976 prices (excluding inflation) would be required before a flakeboard plant would be considered feasible in the Northern Rockies.

Introduction

The northern Rocky Mountain region is a mountainous area about 300 miles wide and 600 miles long that lies in a broad band from just south of Yellowstone National Park, north to Canada. To the south there are large, high plateaus and gently rolling hills, while to the north the land is steep and rugged. Most of the area is heavily forested with mixed conifers, with lodgepole pine, Douglas fir, and western larch being the dominant commercial species.

Two sites within this area have been selected representative of the whole region: St. Anthony, Idaho, in southeast Idaho adjacent to Yellowstone Park, and Missoula, Montana, in the northern mountains.[2] The forest residues available to a structural flakeboard plant in Missoula will consist primarily of dead or down timber and small stems that will become available as an adjunct to logging for veneer and sawlogs. The wood will be a mixture of lodgepole pine, Douglas fir, and western larch, with some alpine fir. St. Anthony is adjacent to large tracts of dead lodgepole pine, the result of a recent infestation of mountain pine bark beetle. The trees are mostly standing dead, with heavy concentrations in many areas. Some of this material will become available as an adjunct of normal logging operations, but most would be harvested as sales of dead timber. Most of the dead wood is sound, but has large checks which make portions of it unsuitable for lumber or veneer use.

Residue Volumes[3]

Volumes of forest residues in western Montana have been estimated based on current harvesting plans for sawlogs. The actual volumes of residues will vary considerably according to what part of the total biomass is considered as available residues. Only stems, or parts of them, that are sound enough and large enough to pick up and haul on a log truck have been considered for this analysis. Based on the current average of about 100,000 acres per year in western Montana that is harvested for sawlogs, there should be about 75 to 120 million cubic feet of useable forest residues generated per year. That is enough fiber to supply

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[1]Richard P. Withycombe is Assistant Professor of Management and Research Associate of the Bureau of Business and Economic Research, School of Business Administration, University of Montana, Missoula. This paper is based on a cooperative study between the University of Montana and the USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain.

[2]The named cities are representative of a geographical area with a radius of about 200 miles. The analysis which follows applies to this broad area, and is not necessarily limited to the two cities named.

[3]Volume estimates in this section were furnished by Bob Benson, Forest Sciences Laboratory, Missoula, Montana (based on a summary of Mountain States forest residues manuscript in preparation).

from 10 to 15 structural flakeboard plants, each one producing 150 million square feet of one-half inch flakeboard per year. The estimates of the available volumes of forest residues are subject to considerable error, but there is no doubt that there is a sufficient volume to furnish several flakeboard plants.

The forest residues in Southeastern Idaho consist primarily of standing dead lodgepole pine, the result of an epidemic infestation of mountain pine bark beetle. There is an estimated 668 million cubic feet of dead timber in the area. The Targhee National Forest would prefer to harvest this timber within the next 15 years, which would make about 50 million cubic feet per year available for products.

Not all of the estimated total volumes in either area would actually be available for production of flakeboard. Much of the material in both regions is in remote areas far from roads. A portion of those areas may eventually be classified as wilderness, or be otherwise reserved from harvest. The estimates for western Montana should be reduced by about one-third, and those for the Targhee should be reduced by as much as one-half to account for those areas that may not be harvested.

There is some current utilization of forest residues in both areas. At times when the national (or international) market for pulp chips is strong, and other supplies are short, pulp chips are produced from dead timber, but most of the time the cost of harvesting and shipping the chips exceeds their market value, so that there is little collection of forest residues for chips. House logs are produced throughout the area, and there is a constant but relatively small market for posts and poles from dead or small timber. Considerable volumes of recently dead lodgepole are sawn for what lumber may be obtained from them, with much of the stem going to pulp chips.

Even after reducing the estimated total volumes of forest residues by 30 to 50 percent because of inaccessibility, and a further 10 to 20 percent for competing uses, there still remains about 50 million cubic feet per year in western Montana, and about 20 million cubic feet per year in Southeastern Idaho, or enough to supply eight large flakeboard plants from the two areas combined.

Harvesting Costs

In estimating the harvesting costs for western Montana, it has been assumed that the residue would be harvested along with normal logging operations, so that all costs of road building, road maintenance, and slash treatment will be borne by the saw and veneer logs. The only costs allocated to the residues will be the costs of falling, yarding, loading, transportation, and chipping. It is further assumed that all residues will be hauled as logs to a central chipping facility, rather than be chipped in the woods. Previous experience has indicated that in the generally steep terrain of western Montana a central chipping facility results in a lower total cost than does in-woods chipping by portable chippers.

The harvesting costs for western Montana are estimated at $22.38 per oven dry ton. The estimate was based on "Timber Production Costs" published by the Bureau of Land Management. The assumptions and the calculation of the estimated costs are shown in Table 1.

The harvesting of dead lodgepole in the St. Anthony area could be handled by conventional logging techniques, but the costs would tend to be somewhat higher than for Western Montana because of the small stem size. The generally flat terrain and small stem size make the use of mechanical harvesting techniques feasible. Table 2 shows a projected cost of $29.91 per ODT, based on the use of a feller buncher with delimbing attachments, a grapple skidder, and a portable de-barking and chipping machine.

In-woods chipping appears to cost somewhat more than a central chipper per ton of chipped wood, but there are some offsetting costs savings. The transportation cost has been estimated as 70 percent of that required to haul logs because of the greater bulk density of the chips. (This assumes that the road system can accommodate the chip truck.) In-woods chipping eliminates the need for bark disposal at a central chipper, and should also result in more complete utilization of the available fiber, since small pieces and tops that would not be hauled on a truck can be chipped. Slash treatment costs have also been reduced in the estimated cost of harvesting by mechanical harvester and in-woods chipping. The dry, brittle lodgepole branches tend nearly to disappear after they have been snapped off by the delimber and trampled a bit by the skidder, and the in-woods chipper eliminates cull logs or short tops that would be left as a result of conventional logging. The end result is a remarkably clean site that will require very little post-harvesting effort.

Production Costs for Structural Flakeboard

The costs of structural flakeboard production (exclusive of wood cost) are nearly the same for all sites in the northern Rocky Mountain region. The cost

of plant and equipment, land, the cost of capital, and taxes are relatively uniform across the United States. There are, however, some significant differences between areas in the costs of labor, energy, and wood.

The cost of labor in the northern Rocky Mountains is about 10 percent lower than for similar jobs in the west coast states, but is much higher than the south or east. Energy costs (both electrical and fuel oil) are slightly lower than the west coast, and much less than the south or east. The total production costs, excluding wood, are about the same as for the west coast sites, but are about 15 percent to 24 percent higher than the east and south.

Figures 1 through 4 show the total production cost as a function of the wood cost. The two lines on each chart represent two of the assumed mixes of raw material, with 40 percent logs and 60 percent chips, or 40 percent flakes and 60 percent chips. The line for the mix using logs is higher in all cases because of the greater cost for chipping and drying the log furnish. Figures 1 and 3 are for a press size of 4 by 16 feet, and figures 2 and 4 are for press sizes of 8 by 24 feet. The economies of scale obtained by the greater press size is apparent.

The estimated sales price at the mill is shown as a horizontal dashed line. The price was derived by assuming a primary market in the Bismark, North Dakota,area for both mill sites. The average 1976 price of $196 per thousand square feet (Mft^2) for one-half inch CDX plywood was reduced by the shipping charges to obtain f.o.b. mill prices of $145 per Mft^2 one-half inch basis for St. Anthony, and $141 per Mft^2 for western Montana.

The break-even cost is shown (where positive) on each figure. In all cases, the break-even cost is significantly below the anticipated cost of harvesting forest residues, so that structural flakeboard production in the northern Rocky Mountain area does not appear to be economically feasible. In order to be feasible, with the estimated wood costs for the two sites, a sales price of $160 f.o.b. mill for St. Anthony, or $153 for the northern Rocky Mountains is required. These represent the break-even prices for the larger press size and a furnish mixture of 40 percent flakes and 60 percent chips. The break-even prices are about 10 percent to 14 percent higher than the 1976 prices.

The primary reason for the dim outlook for structural flakeboard production in the northern Rocky Mountain area is, of course, the cost of transportation to distant markets. Of the sixteen sites selected as representative of probable manufacturing sites in the United States, western Montana has the lowest price f.o.b. mill after adjusting for transportation, and St. Anthony is the third lowest. The effects of distance are even more severe when structural flakeboard is considered a competitor of plywood. If both can be sold at the same price at their destination, the greater weight of flakeboard will necessitate a lower price at the mill; and the difference will be greater for greater distances. With Bismark the assumed market for flakeboard from western Montana, the difference in transportation costs of flakeboard and plywood is $7 per Mft^2, one-half inch basis. For shipment to the East Coast, the difference is $10. (This assumes weights of 1873 lb per Mft^2 for flakeboard and 1500 lb per Mft^2 for plywood.)

A small structural flakeboard mill serving the nearby markets would escape the high transportation costs, but the costs of production for a small plant make this alternative appear inadvisable.

Table 1. - RESIDUE HARVESTING COST ESTIMATES--WESTERN MONTANA

Falling and Bucking[1]	$ 7.60/mbd.ft.
Yarding and Loading[2]	7.35/mbd.ft.
Transportation[3]	19.81/mbd.ft.
Cost to Mill	$34.76/mbd.ft.
Cost per O.D.T. @1 mbd.ft. = 2 O.D.T.	17.38/O.D.T.
Debark and Chip	5.00
Net Cost	$22.38/O.D.T.

(1,2,3) Notes 1,2, and 3 refer to: Timber Production Costs Schedule 20 United States Department of the Interior, Bureau of Land Management, Oregon State Office, Portland, Oregon June 20, 1977

(1) Illustration 1, page 1. Assumed values are:
Average DBH = 12 inches
Percent Top Loss - 20%

(2) Illustration 2, page 4. Assumed values are:
Average Volume per 16 foot log = 80 bd.ft.
Average Yarding Distance = 500 feet
Yarding Method - Tractor

(3) Section .34B, Charts 1,2,3,4, and 5. Assumed values are:
Hard Surface Distance = 30 miles
Gravel Surface Distance = 10 miles
Dirt Surface Distance = 5 miles
Rate of Rise and Fall = 10-20 percent

Table 2. - RESIDUE HARVESTING COST ESTIMATES--ST. ANTHONY, IDAHO AREA

Fall and Limb (Mechanical Harvester)[1]	$ 5.78/O.D.T.
Yard (Grapple Skidder)[2]	5.06
Chip[3]	9.90
Transportation[4]	6.93
Basic Cost	$27.67/O.D.T.
Road Maintenance[5]	1.09
Fire Protection[6]	.40
Fuel Treatment[7]	.75
Total Cost	$29.91/O.D.T.

(1) Fulkema, M.P. Evaluation of Kockums 880 "Tree-King" Feller-Buncher, Technical Report No. TR-13, Forest Engineering Research Institute of Canada, Vancouver, B.C. April 1977

Estimated values are: Economic Life = 14,000 hours, Utilization = 70%, Maintenance Cost = $17/hour, Productivity = 800 cubic feet per hour.

(2) Legault, R., and L.H. Powell. Evaluation of FMC 200 BG Grapple Skidder, Technical Report No. TR-1, Forest Engineering Research Institute of Canada, Vancouver, B.C., December 1975

Estimated values are: Economic Life = 12,000 hours, Utilization = 70%, Maintenance Cost = $15/hour, Productivity = 800 cubic feet per hour.

(3) Sampson, G.R., H.E. Worth, and D.M. Donnely. Demonstration Test of In-Woods Pulp Chip Production in the Four Corners Region, USDA Forest Service Research Paper RM-125, July 1974, page 13.

(4) Calculated as 70% of log transportation costs, Table 1.

(5,6,7) Timber Production Costs Schedule 20 United States Department of the Interior, Bureau of Land Management, Oregon State Office, Portland, Oregon, June 20, 1977. Road Maintenance based on 10 miles gravel and 5 miles dirt, (illus. 4, p. 22). Fire Protection based on small scale, trailer with mounted pump (illus. 5, p. 1). Fuel Treatment based on machine piling and burning, reduced by one-half to account for low residue volume. Assumed 40 O.D.T. per harvested acre (illus. 5, p. 3).

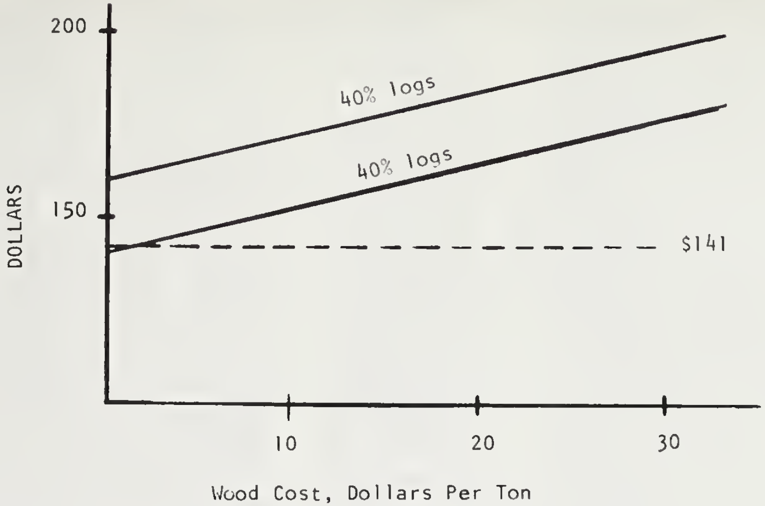

Figure 1
Production Costs - Western Montana
4 x 16 Press Size

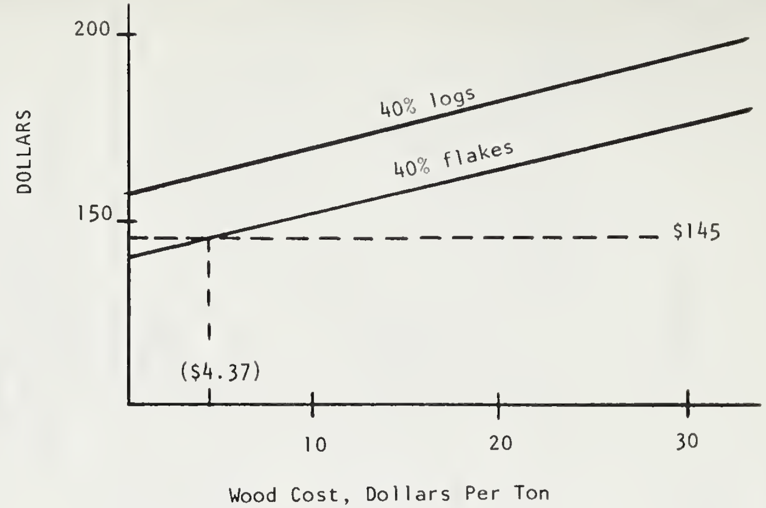

Figure 3
Production Costs - St. Anthony
4 x 16 Press Size

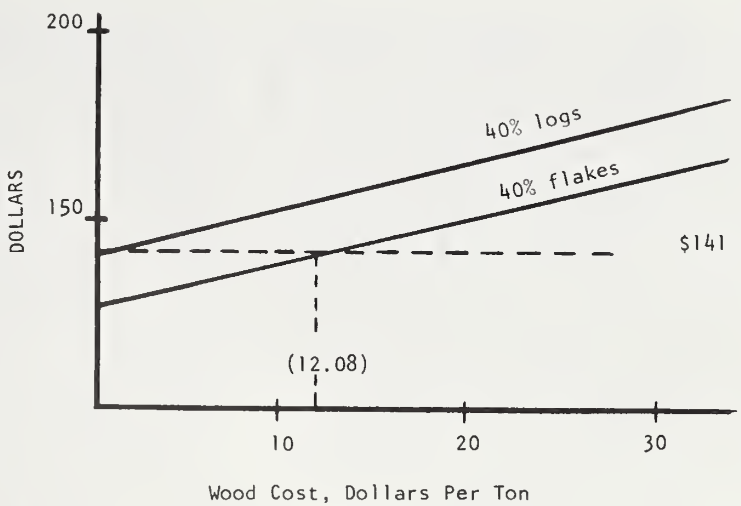

Figure 2
Production Costs - Western Montana
8 x 24 Press Size

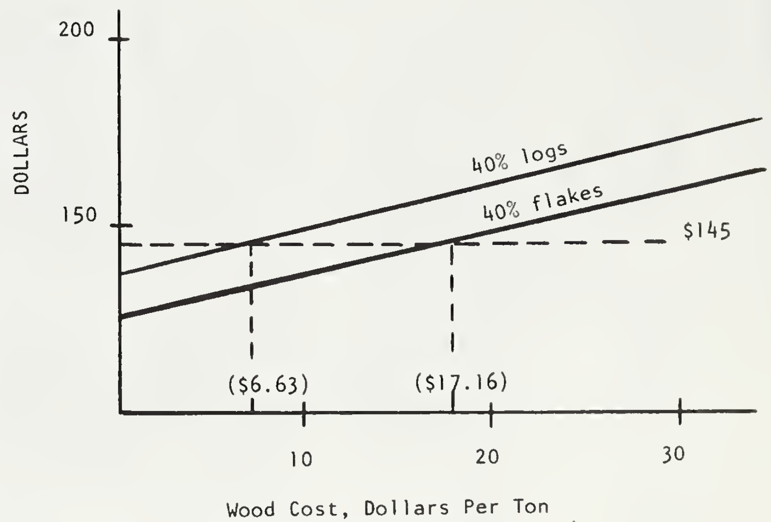

Figure 4
Production Cost - St. Anthony
8 x 24 Press Size

OPPORTUNITIES FOR STRUCTURAL FLAKEBOARD PRODUCTION IN THE PACIFIC NORTHWEST

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Abstract

Feasibility of structural flakeboard manufacture in Washington and Oregon was explored as part of the national program to develop a new product that could help meet rising demand for future building products. The raw material would come chiefly from forest residue, little-used species, and small or defective trees.

Sufficient raw material now exists in Washington and Oregon for a number of structural flakeboard plants, but collection and processing the raw material to uniform clean flakes at a plant site would be costly. Forest industries are well developed in these two States and could easily expand into production of structural flakeboard. It is, however, unlikely that structural flakeboard production from the Pacific Northwest can compete with the same type of board produced closer to distant markets, nor with conventional plywood in western markets.

Introduction

A large share of the timber harvest in Washington and Oregon comes from old-growth forests, with some of the Nation's highest levels of logging residue. In addition, both States contain large areas of lodgepole pine and associated species killed by recent forest insect epidemics. Other types of forest residue include natural mortality, little-used species (chiefly hardwoods), and undesirable growing stock trees. The Forest Residues Program at the Pacific Northwest Forest and Range Experiment Station is looking for ways to reduce forest residue by treatment, improved logging systems, and increased utilization. Structural flakeboard is one class of product that can be made from forest residue (2,3,5,6). This study analyzes the economic feasibility of structural flakeboard production at three representative locations: Longview, Washington, and Medford and La Grande, Oregon.

Structural flakeboard is composed of thin wafers or flakes approximately 2-1/2 inches long. These produce a building board panel intended to be competitive in strength qualities to sheathing grades of softwood plywood. If structural flakeboard can be produced at a lower cost than plywood, it should be able to help stretch the Nation's raw material supply in the long-term, growing housing market (1,7).

Washington and Oregon are strongly oriented toward the forest industries, and these States already have the related technology, managerial ability, and skilled labor force employed in conventional particleboard manufacture. Existing particleboard operations are well integrated with other forest industries in matters of raw material supply and end-product sales functions and without much difficulty could expand into production of structural flakeboard. The main question is one of economics--whether or not structural flakeboard from the Pacific Northwest can compete with the same type of board produced closer to distant markets, chiefly in the Midwest and Eastern States, or whether it can compete with conventional plywood in western markets.

Quantity and Availability of Forest Residue Materials

The greatest total volume of forest residue, as well as volumes per acre, occur as logging residue associated with clearcutting in the Douglas-fir region of western Washington and western Oregon. Howard (4) estimated this annual production, including limbwood, to be 465 million cubic feet for 1969, a fairly typical year. Average net volume of logging residue was 1,344 cubic feet per acre on private lands, 3,153 cubic feet per acre on National Forest lands, and 2,054 cubic feet per acre on other public lands (Table 1). These volumes do not include pieces less than 4 inches in diameter outside bark and 4 feet in length.

Similarly, in eastern Washington and eastern Oregon, Howard estimated the logging residue from all types of logging to be 93 million cubic feet, averaging 376 cubic feet per acre on private lands and 312 cubic feet per acre on public lands.

In addition, there is an estimated 227 million cubic feet of standing dead timber, mostly lodgepole pine, killed from 1968 through 1977 by the mountain pine beetle in eastern Washington and eastern Oregon. Most of this is in the Blue Mountains of northeastern Oregon.

Other types of forest residue, not associated with logging, such as normal mortality, hardwoods, and undesirable growing stock trees, are mostly widely scattered and are not considered to be feasible sources for utilization except

Table 1. - NET VOLUME OF LOGGING RESIDUE IN WASHINGTON AND OREGON, 1969

	Total volume	Bucked log	Breakage	Full tree or top	Limbwood	Slabs and splinters
	(Million cubic feet[1])					
Douglas-fir region						
National Forest	142.8	75.7	46.0	12.8	1.8	6.5
Other public	102.7	48.8	27.1	17.9	1.4	7.5
Private	219.8	31.4	103.4	55.9	2.6	26.6
	465.3	156.0	176.4	86.6	5.8	40.6
Ponderosa pine region						
National Forest[2]	64.0	14.4	11.7	33.4	4.3	0.2
Private	29.0	2.3	8.5	14.9	1.9	1.5
	93.0	16.7	20.2	48.3	6.2	1.7
Total	558.3	172.6	196.6	134.9	11.9	42.2

[1]Data may not add to totals because of rounding.

[2]Includes some land owned or administered by other public agencies.

Source: Developed from Table 15 of Howard (4).

as they can be taken out along with sound material in regular harvest operations.

Quantities of annual logging residue in three geographic areas were estimated, based on the relation of log harvest to logging residue in the base year 1969, for which logging residue data are available. These areas included:

1. Clark, Cowlitz, Lewis, and Wahkiakum Counties, Washington, and Columbia County, Oregon (potential utilization center Longview, Washington);

2. Josephine and Jackson Counties, Oregon (potential utilization center Medford, Oregon); and

3. Umatilla, Union, Baker, and portions of Grant and Wallowa Counties, Oregon (potential utilization center La Grande, Oregon).

The above estimates include only the material classified by Howard as 41 percent or more chippable and were reduced by 10 percent to allow for material that would be too scattered or too far from a potential landing to be economically harvested.

Results are expressed in terms of amounts within a hauling distance of either 40 or 60 miles for Longview and Medford areas, and 50 or 80 miles for the La Grande area in eastern Oregon (Table 2). These hauling distances reflect the radius within which a prospective plant might plan to obtain the majority of its raw material. Actual plant locations might be anywhere within the corresponding geographic area. Where amounts shown are insufficient to support one structural flakeboard plant, additional raw material would have to come from green timber, which could include sanitation cuttings, fire salvage, and silviculture thinnings.

Of the 227 million cubic foot backlog of insect-killed timber in eastern Washington and eastern Oregon, the three National Forests most directly concerned (Umatilla, Malheur, and Wallowa-Whitman) estimate that up to 40 percent or 90.8 million cubic feet are not likely to be harvested in 20 years, because of such things as lack of roads, small tree size, low volumes per acre, or high harvest costs. This leaves 136.2 million cubic feet potentially available for harvest, which amounts to 6.8 million cubic feet annually for 20 years.

Table 2. - LOGGING RESIDUE AND INSECT-KILLED TIMBER AVAILABLE ANNUALLY IN THREE GEOGRAPHIC AREAS, AND NUMBER OF POTENTIAL STRUCTURAL FLAKEBOARD PLANTS

Residue type and geographic area	Available annual amount	Number of potential flakeboard plants (37.5 MM ft^2 1/2 inch)
	(Million cubic feet)	
A. Logging residue		
Southwestern Washington (Longview)		
40 mile radius	13.3	4.2
60 mile radius	30.0	9.5
Southern Oregon (Medford)		
40 mile radius	5.9	1.9
60 mile radius	13.2	4.2
Eastern Oregon (La Grande)		
50 mile radius	2.9	0.9
80 mile radius	7.3	2.2
B. Insect-killed timber		
Eastern Oregon (La Grande)		
50 mile radius	2.7	0.8
80 mile radius	6.8	2.1

Source: Developed by Forest Residues Research, Development, and Application Program, Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service, Portland, Oregon.

Utilization of forest residue for structural flakeboard must be able to meet the competition from other potential products such as lumber, veneer, pulpwood chips, and fuel for energy. Except for energy, these products tend to have a higher value, and hence would probably be able to bid the raw material away from structural flakeboard manufacture. Thus, physical availability of forest residue in the forest is not the same as economic availability to a given manufacturing plant.

Economic availability of forest residue material for structural flakeboard depends on such things as distance to a potential utilization center, road accessibility, volume per acre, contractual arrangements with the landowner, and the residue material's competitive value for a variety of potential products.

New manufacturing plants need some kind of assured raw material supply for their planned amortization period, usually around 10 to 20 years. As with regular timber sales on the National Forests, it may be sufficient for a large, strong firm that raw material will continue to be competitively available. It may, however, be difficult for a smaller firm to obtain sufficient logging residue from a large number of public timber sales to others.

Costs of Harvesting

Costs of harvesting forest residue-type materials were developed using the U.S. Forest Service, Region Six Appraisal Handbook as a guide (Table 3). Firmwood scaling defect, based on potential recovery of flakes rather than lumber or veneer, was estimated at 20 percent in the Longview and Medford areas, and 10 percent in the La Grande area.

Stumpage cost for potential flake-

Table 3. - ESTIMATED COST OF DELIVERED WOOD TO MANUFACTURING SITES, 1976[1]

	Longview, WA	Medford, OR	La Grande, OR
	(Dollars per fbm net firmwood scale)		
Felling and bucking[2]	--	--	10.71
Yarding	17.56	17.56	15.98
Loading	4.46	4.46	4.58
Overhead	2.48	2.48	3.97
Depreciation	2.87	2.87	2.27
Woods fire protection	.43	.43	.47
Transportation			
40 miles	21.22	21.22	--
50 miles	--	--	32.92
	49.02	49.02	70.90
Differential for low volume per acre (Medford), and deterioration prior to harvest (La Grande), 10 percent	--	4.90	7.09
Stumpage	.50	.50	.50
	49.52	54.42	78.49
Profit and risk allowance, 10 percent.	4.95	5.44	7.85
	54.47	59.86	86.34
Equivalent cost per cunit (@5.5 fbm/ft^3)	(29.93)	(32.89)	--
(@5 fbm/ft^3)	--	--	(43.17)
Cost per oven dry ton (@78.1363 ft^3/OD ton)	(23.39)	(25.70)	--
(@82.1433 ft^3/OD ton)	--	--	(35.46)

[1]Developed from U.S. Forest Service, Region Six Appraisal Handbook.

[2]Material near Longview and Medford is assumed to be logging residue requiring little or no bucking; material near La Grande is assumed to be mostly standing dead trees.

board logs was estimated at $0.50 per thousand board feet in all areas, recognizing that some logs would have a higher value for other products and be assigned a higher stumpage value. A profit and risk allowance of 10 percent was also applied, on the basis that the largest share of wood supply would probably be purchased wood.

The resulting costs were converted to costs per cunit[1] at 5.5 board feet per cubic foot (Longview and Medford areas) and 5 board feet per cubic foot (La Grande area). Costs per oven dry ton were then calculated at 78.1363 cubic feet per oven dry ton (Longview and Medford areas) and 82.1433 cubic feet per oven dry ton (La Grande area). The resulting costs were then rounded to $23, $26, and $35 per oven dry ton, respectively, for delivered wood in the three areas.

These costs are our best estimate of average costs under realistic operating conditions. Actual costs of harvesting small pieces, as from tops and limbs, could exceed these amounts by a wide margin if harvesting is by regular logging equipment. Chipping or flaking of

Table 4. - ESTIMATED COSTS OF PRODUCTION FOR STRUCTURAL FLAKEBOARD, INCLUDING WOOD COSTS, AT LONGVIEW, WASHINGTON, AND MEDFORD AND LA GRANDE, OREGON, 1976

Site and wood supply	Annual production and press size			
	37.5 MM ft^2 4 x 8 ft	75 MM ft^2 4 x 16 ft	112.5 MM ft^2 4 x 24 ft	150 MM ft^2 8 x 24 ft
	(Dollars per M ft^2 1/2-inch basis)			
Longview, Washington				
100% flakes	211.35	--	--	--
40%/60% flakes/chips	224.93	182.56	169.53	167.14
40%/60% logs/chips	245.76	196.26	180.31	175.58
Medford, Oregon				
100% flakes	213.89	--	--	--
40%/60% flakes/chips	227.90	184.51	171.13	168.81
40%/60% logs/chips	251.31	200.47	184.10	179.33
La Grande, Oregon				
100% flakes	212.90	--	--	--
40%/60% flakes/chips	226.91	183.85	170.47	167.82
40%/60% logs/chips	254.94	204.37	188.00	182.80

Source: Derived from estimating equations developed at U.S. Forest Products Laboratory, Madison, Wisconsin.

small pieces in the woods could reduce wood costs somewhat, but costs for small pieces would still be higher than for larger pieces.

Costs of Manufacturing Structural Flakeboard

Costs of manufacturing were estimated for three types of wood raw material supply (flakes, flakes/chips, and logs/chips), four press sizes, and four plant sizes ranging from 37.5 million- to 150 million-square foot annual production, 1/2-inch thickness.

Actual production could be in 3/8-, 1/2-, 5/8-inch, or other thickness, but all costs are shown in this report on a 1/2-inch basis. The cost calculations include a 15-percent rate of return on investment, using a discounted cash flow analysis developed at the U.S. Forest Products Laboratory, Madison, Wisconsin.

Resulting costs of production, including wood costs, range from $167.14 per M square feet, 1/2-inch basis (Longview 150 MM ft^2 per year, 40-percent flakes and 60-percent chips) to $254.94 per M square feet (La Grande, 37.5 MM ft^2 per year, 40-percent logs and 60-percent chips) (Table 4). These are calculated using $33 per oven dry ton cost of purchased chips ("Maxi-chips" 2 to 3 inches in length), and delivered logs costs of $23, $26, and $35 per oven dry ton in Longview, Medford, and La Grande, respectively.

Estimating equations were developed to permit calculating production costs for any wood cost (Table 5). These may be used to calculate the effect on total production costs of any increase or decrease in wood cost or to calculate the amount of change in wood cost necessary to achieve a given target for total production cost.

Likely Market Value of Structural Flakeboard

The principal potential market for structural flakeboard is for 1/2-inch sheathing panels corresponding to 1/2-inch CD exterior grade softwood plywood. In order to compete with softwood plywood it was assumed that structural flakeboard would have to sell at 10 percent or more under the price of softwood plywood.

Los Angeles was chosen as an assumed primary market for structural flakeboard

Table 5. - ESTIMATING COEFFICIENTS FOR CALCULATING PRODUCTION COSTS FOR STRUCTURAL FLAKEBOARD AT LONGVIEW, WASHINGTON, AND MEDFORD AND LA GRANDE, OREGON, 1976[1]

Site and wood supply	Press Size							
	4 x 8 ft		4 x 16 ft		4 x 24 ft		8 x 24 ft	
	a	b	a	b	a	b	a	b
	(Dollars per M sq.ft. 1/2-inch basis)							
Longview, Washington								
100% flakes	169.77	1.26	--	--	--	--	--	--
40%/60% flakes/chips	183.35	1.26	141.64	1.24	128.61	1.24	126.88	1.22
40%/60% logs/chips	208.35	1.29	159.43	1.27	143.48	1.27	139.33	1.25
Medford, Oregon								
100% flakes	172.31	1.26	--	--	--	--	--	--
40%/60% flakes/chips	186.32	1.26	143.59	1.24	130.21	1.24	128.55	1.22
40%/60% logs/chips	212.35	1.29	162.12	1.27	145.75	1.27	141.58	1.25
La Grande, Oregon								
100% flakes	172.31	1.23	--	--	--	--	--	--
40%/60% flakes/chips	186.32	1.23	143.59	1.22	130.21	1.22	128.55	1.19
40%/60% logs/chips	212.35	1.26	162.12	1.25	145.75	1.25	141.56	1.22

[1]Production cost ($\$/M\ ft^2$) = a + bX, where a is production cost excluding wood cost, and b is coefficient of wood cost per oven dry ton (X).

from Pacific Northwest plants. In 1976 the wholesale delivered price of 1/2-inch CD exterior grade plywood in Los Angeles was about $185 per thousand square feet. Ninety percent of this would be $166.50. Subtracting representative freight charges from Longview, Medford, and La Grande gave $142.17, $147.47, and $142.73 per thousand square feet, respectively, as the target f.o.b. mill price structural flakeboard would have to meet in order to be competitive with softwood plywood (Table 6).

Other primary markets than Los Angeles could have been chosen, such as Seattle, Salt Lake City, San Francisco, or Omaha; however, subtraction of freight costs from these markets should give about the same target f.o.b. mill prices as to Los Angeles.

Conclusions

Comparison of production costs with target f.o.b. mill prices indicates that at 1976 costs and prices structural flakeboard would not be competitive with 1/2-inch CD exterior grade softwood plywood, under the requirement that structural flakeboard undersell softwood plywood by 10 percent and earn a 15-percent rate of return on investment.

Using the regression coefficients shown in Table 5, we find that target f.o.b. mill prices could, however, be met in the larger size plants if wood costs could be reduced to $10 to $12 per oven dry ton in the Longview and La Grande areas, and $15 to $17 per oven dry ton in the Medford area. Such low costs for wood supply seem unlikely. Alternatively, a price rise of $25 to $30 per thousand square feet for 1/2-inch CD exterior grade softwood plywood, without any increase in costs for structural flakeboard, would put flakeboard within the competitive range in western markets.

Remodeling older particleboard plants might offer a chance to save on initial investment cost, but this would be offset at least in part by higher operating costs.

Analysis of data reported from Eastern and Southern United States potential sites for production of structural flakeboard indicates that those sites are in a much more favorable position to compete with softwood plywood in their market areas. This is due to 1) the higher market price of plywood in eastern markets, 2) the lower freight costs for structural

Table 6. - CALCULATION OF TARGET F.O.B. MILL PRICES FOR 1/2-INCH STRUCTURAL FLAKEBOARD TO BE COMPETITIVE WITH CD EXTERIOR GRADE 1/2-INCH SOFTWOOD PLYWOOD, 1976

Plant location	Softwood plywood CD-exterior: Los Angeles market price	Structural flakeboard: Competitive price	Structural flakeboard: Freight cost	Structural flakeboard: Target f.o.b. mill price
	(Dollars per M ft^2, 1/2-inch basis)			
Longview, Washington	185	166.50	24.33	142.17
Medford, Oregon	185	166.50	19.03	147.47
La Grande, Oregon	185	166.50	23.77	142.73

flakeboard from eastern and southern sources, and 3) lower costs for labor and raw materials.

In conclusion, it appears that structural flakeboard from the Pacific Northwest, as of 1976, could not compete with flakeboard produced closer to eastern and southern markets, nor could it compete effectively with CD exterior grade softwood plywood in western markets without a substantial price rise for the competing plywood.

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OPPORTUNITIES FOR FLAKEBOARD PRODUCTION IN NORTHERN CALIFORNIA

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Abstract

Logging-type residues available within 200 miles of Arcata, Calif. average about 100,000 ovendry tons per year. Another 518,000 tons of mill residues are available annually from the same area. Wood residue volumes appear sufficient to support wood requirements for at least one large structural flakeboard plant. Estimates of wood supply cost (1976 basis) range from about $26 to $35 per ovendry ton, depending upon form and transportation distance. Economic analysis indicates that an efficently sized structural flakeboard plant should be able to support wood costs for logs and chips ranging up to $38 per ovendry ton or higher depending upon product market value.

Techniques for the production of structural flakeboard products from hardwood and softwood logging residue-type materials have been determined. Additionally, the costs of manufacturing structural flakeboard products from logging residues have been estimated for four different sizes of facilities for northern California sites. Facility operating costs, excluding wood costs, have also been estimated for an Arcata, Calif. site. The objective of this paper is to present estimates of available annual volumes and harvesting costs of logging residues, to provide estimates of structural flakeboard production costs which include wood costs, and to assess the economic feasibility of manufacturing structural flakeboard from a northern California site.

California Forest Resources

Development of the forest industry in California began with the discovery of gold in 1848 (4). Early logging and milling activities were confined to the more accessible coastal areas and the mining centers in the central Sierra Nevada. Following the initial period of mining activity, population increases and resultant growth of coastal and interior cities resulted in a continued growth of wood products manufacture--primarily in the regions north of the San Francisco latitude. The northern regions of California account for about 77 percent of the available commercial forest area in California--about 13 million acres.

The long history and localized nature of the forest industry in California have resulted in a forest resource of complex structure. Large areas of mature second-growth timber are found concentrated in the more accessible North Coastal and Central Sierra areas of the State, primarily on private land. But, there are still large areas of National Forest lands stocked with old-growth sawtimber. Also, the forests of northern California are highly differentiated due to the climatic influence of the coastal mountain ranges; the result is the heavily stocked redwood-Douglas-fir stands of "west side" coastal influence and the more sparsely stocked pine-fir stands of the "east side" inland influence (Fig. 1).

Over the past decade, log production from California forests has ranged from 5 to 6 billion board feet (Scribner log scale). About 40 percent of this production is currently form the west side and 47 percent from the east side (2)(4). Between 40 and 50 percent of total log production is obtained from National Forest lands.

Availability of Forest Residue

Per acre volumes of available logging residues vary sharply because of differences between the pine-fir stands of the east side and the redwood-Douglas-fir stands of the west side, different harvesting systems used, and cull-log demand. One study indicated that west side areas average about 2,755 cubic feet of logging-type residues per acre (net volume). The east side averages only 400 cubic feet per acre (3). In view of this information, analysis of the feasibility of manufacturing structural flakeboard was confined to consideration of a west side site (Arcata, Calif.) that could efficiently draw upon major concentrations of logging residues.

Cruise defect of west side National Forest timber averages around 30 percent of gross stand volume, or about 35,000 board feet (Scribner scale) per acre (5). Correspondingly, scaling defect of log harvests averages about 25 percent of gross scale volume, reflecting a substantial volume of chippable and peelable cull log removal. Slash volume left in the woods from over 4,150 acres of yearly regeneration harvest from west side National Forest lands amounts to about 1,460 cubic feet per acre.

About 55 percent of the total logging

reside volume is obtainable without new road construction, which could supply about 3.3 million cubic feet or about 50,000 ovendry tons of logging residues per year (28 and 37 lbs. per cu. ft., dry weight green volume basis, respectively for softwoods and hardwoods) from National Forest harvests (Table 1). About 30 percent of this volume might be of mixed hardwood species.

An equal or greater volume of log production is obtained from State and private forest lands, but in many areas from second-growth stands yielding less than old-growth stand averages of logging residues. A reasonable estimate of total logging residue volume available to an Arcata manufacturing site might be about twice the volume available from the National Forest, or about 100,000 ovendry tons per year.

Also, partly due to chippable and peelable cull log harvest, 2.8 million ovendry tons of softwood manufacturing residues were generated in 1973 (2). About 1.8 million tons of these residues were reported to have been used as fuel or for the production of other wood and wood fiber products. About 900,000 tons of these residues were reported to have been unused. In 1974, a survey of 70 mills in Humboldt County indicated the availability of about 518,000 tons of unused softwood sawmill residues within a distance of 200 miles from the Arcata area (5) (Table 2). These are surplus residue volumes either being burned or buried in landfills. Although these were the dregs of primary manufacturing processes, some volume of these mill residues can be expected to be in the form of sawmill edgings and rims (up to 40 pct.) that could be used for the production of structural flakeboard (1).

Wood Requirements

Structural flakeboard cannot be produced from the customary mixtures of planer shavings and sawdust used for particleboard manufacture. At least 30 percent of the structural flakeboard furnish must be of high quality flake, such as produced from roundwood using a disk flaker or shaping lathe headrig to produce the high-strength faces required for predictable structural performance. Core furnish, up to 70 percent, however, may be prepared by the flaking of maxichips (2 to 3 inches long) using a ring flaker. Consequently, roundwood and other forms of unchipped residues are needed to supply at least 30 percent of the wood raw material for structural flakeboard manufacture.

Four different sizes of structural flakeboard facilities were analyzed. Investment costs for the largest facilities were about three times those for the smallest facilities considered, and wood raw material requirements ranged from about 40,500 to 156,700 ovendry tons per year (Table 3). Because economies of scale are substantial, and wood raw material supplies become of paramount importance for commercial feasibility, careful consideration needs to be given to choosing the scale of a prospective new facility.

Costs of Harvesting Logging Residues

Costs of mill residues and logging residues differ because slabs, edgings, and veneer cores reflect the joint costs of primary processing. Consequently, the costs of mill residues to a buyer of wood raw materials for structural flakeboard production will probably reflect the going market price for pulp chips. Over the past 5 years pulp chip prices in the Arcata-Eureka area have reportedly ranged from \$20 to \$60 per bone dry unit (2,400 lbs., bone dry wood), or about \$17 to \$50 per ovendry ton. The per-ton costs of harvesting and transporting logging residues are estimated to range from \$26 to \$35 per ovendry ton (Table 4), costs which probably also influence the purchase-or-harvest decisions of pulp chip users.

Production Costs of Structural Flakeboard

Estimated production costs for structural flakeboard at an Arcata, Calif. site have been estimated to range from \$109 to \$191/MSF (1/2-in. basis), excluding wood costs. Production costs vary with the size of the facility, and to some extent with the amount of pre-processing required for utilizing roundwood. That is, processing costs for utilizing roundwood increase structural flakeboard production costs from \$10 to \$37/MSF (1/2 in.) over costs when utilizing chips or flakes. The full costs of producing structural flakeboard, including wood costs, can be estimated by referring to Figures 2 through 5.

Assuming an average wood cost of \$33 per ovendry ton, the full cost of producing structural flakeboard, including wood, is estimated to range from \$149 to \$233/MSF (1/2 in.) when utilizing softwood. Due to the greater weight of hardwoods, chemical and energy costs increase on a per cubic foot basis. For this reason, the utilization of hardwoods would increase production costs up to about 4 percent. Structural flakeboard products would have to be sold at an average f.o.b. mill price (1976 basis) of from \$149 to \$233/MSF (1/2 in.) to support profitable production if wood costs averaged \$33 per ovendry ton (Figures 2 through 5).

Table 1. - Estimated annual volumes of logging residues available within a 200-mile radius of Arcata, California[1]

Logging Residue	Softwoods[2]	Hardwoods[3]	Total
		(1,000 ovendry tons)	
Gross[4]	64.6	27.8	92.4
Net[5]	53.4	22.2	75.6
Net usable[6]	49.2	20.4	69.6
Net available[7]	35.1	14.8	49.9
Net available barkable[8]	35.1	13.9	48.1
Net available non-barkable[9]	0	1.9	1.9

[1]Correspondence: USDA Forest Service, Region 5, May 1974.

[2]Assumes a weight of 28.1 pcf, ovendry, green volume.

[3]Assumes a weight of 37.0 pcf, ovendry, green volume.

[4]Gross volume defined as cubic volume of a piece of residue over minimum diameter of 4 inches and at least 4 feet in length.

[5]Net volume defined as the portion of a piece of residue capable of producing sound pulp chips with a 10 percent minimum recovery, not including rotten, shattered, or missing parts.

[6]Net usable volume is defined as the net logging residue minus limb wood, splinters, and slabs over the minimum dimensions.

[7]Net available volume is defined as logging residue within 600 feet or less of an existing landing.

[8]Barkable residue is that capable of being barked by a mechanical barker.

[9]Non-barkable is the difference between net available volume and barkable volume.

Table 2. - Annual volume of mill residues from 70 operating sawmills within a 200 mile radius of Arcata, California[1]

Distance	Ovendry tons per year
0-50 miles	190,752
50-100 miles	172,600
100-200 miles	154,600
Total	517,925

[1]Correspondence: USDA Forest Service, Region 5, May 1974.

Table 3. - Estimated annual wood requirements for four sizes of structural flakeboard manufacturing facilities

Annual output capacity	Wood raw material requirements
(million square feet, 1/2-inch thickness)	(thousands of ovendry tons)
37.5	40.5
75.0	80.1
112.5	119.8
150.0	156.7

Table 4. - Estimated cost of logging residues at Arcata, California

Type of cost	Cull logs	Chips or flakes
	(dollars per ovendry ton)	
Overhead expense	2.25	2.25
Road construction	NC	NC
Road maintenance	1.00	1.00
Fall and buck	3.50	.50
Yard	11.00	15.00
Debark, chip and/or flake	NC	7.00
Load	2.50	1.00
Total harvest cost	20.25	26.75
Stumpage cost	0.50	0.50
Transportation:		
50-100 miles	5.00	5.00
100-200 miles	7.50	7.50
Total costs:		
50-100 miles	25.75	32.25
100-200 miles	28.25	34.75

NC: no charge.

Likely Market Value of Structural Flakeboard

Although structural flakeboard products might be used as an underlayment grade of CD exterior sheathing and possibly for specialty uses such as for siding and decorative panel use, the primary opportunity would probably be in commodity grades of structural sheathing. Of these products, 1/2-inch-thick plywood, CD exterior grade, is the most predominant product in use. If structural flakeboard products were to compete in the commodity sheathing markets they would probably have to be sold at or below the prevailing market costs for comparable plywood sheathing.

An estimate of the maximum average market value structural flakeboard might have attained during 1976, f.o.b. Arcata, is based on the average market price of CD exterior grade, 1/2-inch plywood f.o.b. Los Angeles, less the higher freight cost of structural flakeboard. The average market price for CD exterior grade, 1/2-inch plywood f.o.b. Los Angeles was about \$185/MSF (1/2 in.) during 1976. Freight costs for 1/2-inch-thick structural flakeboard weighing 1,962 pounds per thousand square feet, 1/2-inch thick, would be about \$15.50 (via rail, 79¢/cwt), indicating an f.o.b. Arcata mill value of about \$169.50/MSF (1/2 in.) (subject to trade discounts of 5, 3, and 2 pct.).

Assessment of Commercial Feasibility

Assessment of commercial feasibility can be made by matching expected production costs of structural flakeboard manufacture against likely f.o.b. mill value of product output (Figs. 2 through 5). For example, the facility producing 112,500,000 square feet of 1/2-inch material per year from flakes and chips, including wood costs ranging from \$30 to \$33 per ovendry ton, indicate production costs ranging from \$150.50 to \$154.25--

substantially less than the estimate of f.o.b. mill market value. Conversely, an f.o.b. mill value of $169.50/MSF could be expected to support wood costs up to $45 per ovendry ton (($169.50 - 113)/1.25).

Using the same method of analysis, commercial feasibility would be indicated as a possibility for all but the smallest of the facilities considered (the facility rated for 37,500,000 SF per year).

Summary and Conclusions

The long history and localized nature of the California forest industry have resulted in a forest resource of complex structure. Also, in the northern California regions which account for about 87 percent of total log production in the State, forests are highly differentiated between the redwood-Douglas-fir stands of west side coastal influence and the pine-fir stands of east side inland influence. Due to differences between the west side and east side forests, different harvesting systems used, and cull-log demand, per acre volumes of available logging residues vary sharply. Because the per acre volumes of logging residues in the west side forests are about six times the volume of those in the east side forest, analysis of the feasibility of manufacturing structural flakeboard was confined to consideration of a west side site (Arcata, Calif.) that could efficiently draw upon major concentrations of logging residues.

It is estimated that about 100,000 ovendry tons of logging residues should be available to an Arcata site within a distance of 200 miles. About 30 percent of this volume would probably be of mixed hardwood species. Additionally, between 500,000 and 900,000 ovendry tons of unused softwood mill residues are generated annually within a 200-mile radius of Arcata. At least 30 percent of the structural flakeboard furnish must be of high-quality flake, such as produced from roundwood using a disk flaker or shaping lathe headrig to produce the high-strength faces required for predictable structural performance. Logging and mill residue supplies appear sufficient to supply the wood raw material requirements for at least a medium-sized structural flakeboard facility.

Estimates of wood supply costs indicate that the per-ton costs (ovendry) of harvesting and transporting logging residues to an Arcata site would range from about $26 to $35. Mill residues of suitable quality for structural flakeboard manufacture would probably range from about $17 to $50 per ovendry ton, depending upon markets for pulp chips.

The full costs of producing structural flakeboard, including wood costs averaging $33 per ovendry ton, are estimated to range from $149 to $233/MSF (1/2 in.) depending upon facility size and amount of roundwood pre-processing required. The average f.o.b. Arcata market value for structural flakeboard products, during 1976, was estimated to be up to $169/MSF (1/2 in.), and to indicate economic feasibility for all but the smallest facility considered.

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Figure 1.- Coastal west-side and inland east side regions of northern California

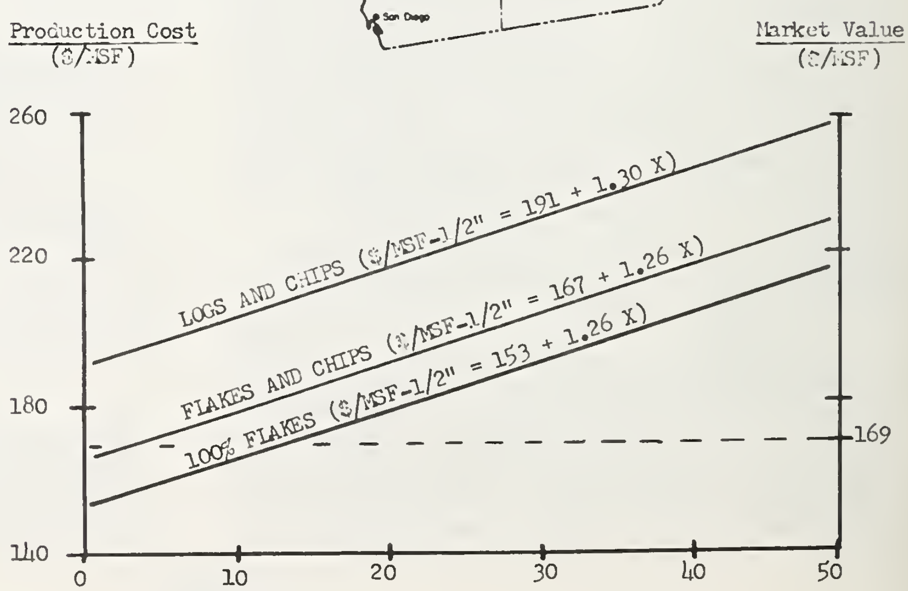

Figure 2.--
Relationship of production cost to wood cost for a structural flakeboard facility rated for 37,500 MSF, 1/2-inch thick, of output per year.

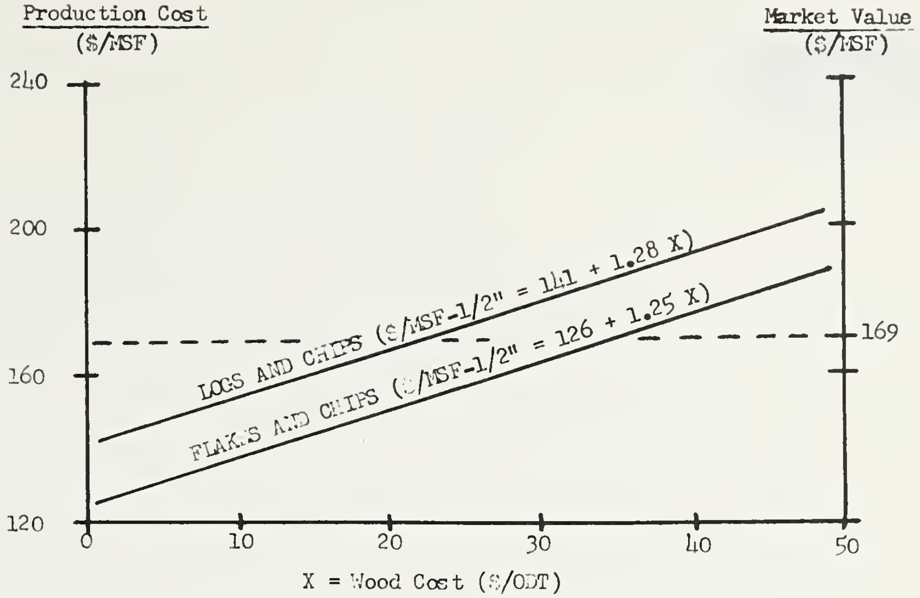

Figure 3.- Relationship of production cost to wood cost for a structural flakeboard facility rated for 75,000 MSF, 1/2-inch thick, of output per year.

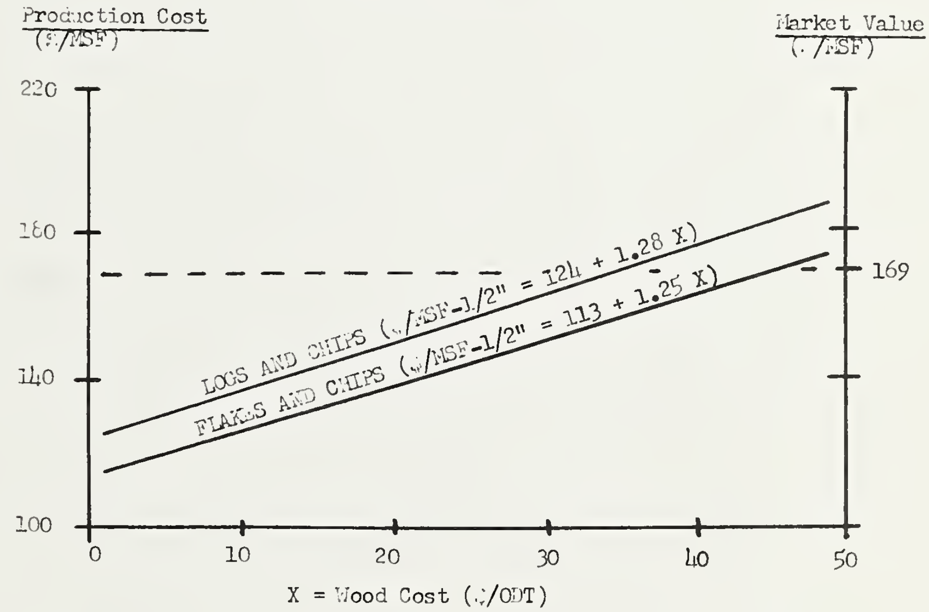

Figure 4.- Relationship of production cost to wood cost for a structural flakeboard facility rated for 112,500 MSF, 1/2-inch thick, of output per year.

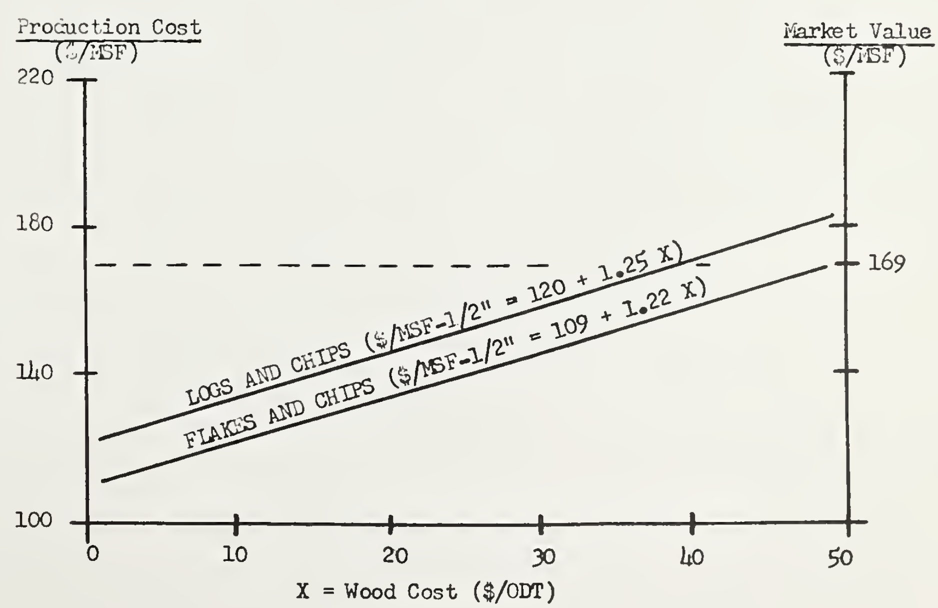

Figure 5.- Relationship of production cost to wood cost for a structural flakeboard facility rated for 150,000 MSF, 1/2-inch thick, of output per year.

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